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ABSTRACT

This study, the fifth in the series "Studies in the Phonology of Asian Languages," aims to describe those acoustic features involved in the distinction of Korean stop consonants, using the sound spectrograph and pitch extractor as research tools. The report specifically deals with voice onset time associated with weak and strong stops and the acoustic quality of voice onset. A condensed version of the paper was presented at the 72nd meeting of the Acoustical Society of America, November 4, 1966. (Author/DD)

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V

ACOUSTIC FEATURES IN THE MANNER-DIFFERENTIATION OF KOREAN STOP CONSONANTS

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PREFACE

This study, Acoustic Features in the Manner-Differentiation of Korean Stop Consonants, is the fifth in the series studies in the Phonology of Asian Languages. It is the result of a research project sponsored by the Office of Naval Research and serves as a technical report for the contract NR 049-183, Nonr 228(28). A condensed version of this study was presented as an oral paper at the 72nd meeting of the Acoustical Society of America, November 4, 1966.

The first volume of the series, Acoustic Phonetics of Korean, Technical Report No. I, was devoted to the acoustic-phonetic study of Korean vowels. The second volume was Duration of Korean Vowels; the third, Acoustic Characteristics of Korean Stop Consonants; and the fourth, Vietnamese Vowels. The present volume is devoted to the study of Korean stop consonants and is a continuation of research that was reported in the third volume.

The purpose and scope of this study as well as the system of transcription are the same as they were in the earlier technical report.

Mieko S. Han

Los Angeles, California
July 1967

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ACOUSTIC FEATURES IN THE MANNER-DIFFERENTIATION OF KOREAN STOP CONSONANTS

Mieko S. Han and Raymond S. Weitzman

INTRODUCTION

One of the aims of a phonological analysis of a language is to discover those qualities that are the physical manifestations of the functionally distinct phonological entities within the language under study. As different languages have different phonemic structures, different languages also make use of different phonetic features in making phonemic distinctions. There are, of course, a number of such features that are shared by a good many languages, but though they share these features, they do not necessarily use them in the same way in making the same phonemic distinctions. In recent years investigations into the relationship between the physical aspects of speech and the functional aspects of speech have been greatly aided by the development of highly sophisticated research tools, such as the sound spectrograph and pitch extractor.

The sound spectrograph is an electro-mechanical device which is capable of visually displaying the acoustic qualities of speech sounds. This is done by analyzing the complex wave

character of speech sounds into their frequency components and recording these on special paper in terms of the three acoustic dimensions frequency, time, and intensity. The pitch extractor is an electronic device consisting basically of an adjustable low pass filter by which it is possible to extract only the fundamental frequency component of a speech wave which is then recorded by a type of data recording system. This device is particularly useful in studying the acoustic parameters associated with such phonological features as intonation, pitch accent, and tone.

The aim of this present study is to describe in part those acoustic features involved in the distinction of Korean stop consonants, using the research tools mentioned above. By a close examination of the data obtained from these instruments, it is possible to compare and measure the acoustic differences between phonologically distinct entities. In this way previous impressionistic observations can be either verified or invalidated, and the analysis results in a better description of the phonology of the language under study.

In Korean a three-way distinction in both the manner and place of articulation serves to differentiate nine stop consonant phonemes, namely, the aspirated bilabial, dental, and velar stops (/p^h/, /t^h/, /k^h/), the weak bilabial, dental, and velar stops (/p/, /t/, /k/), and the strong bilabial, dental, and velar stops (/P/, /T/, /K/).[1]

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[1]Other investigators have called the weak and strong

All Korean stops may occur in word initial position, and in this position they are all voiceless. Likewise, all Korean stops may occur in medial position. However, in this position between voiced sounds, /p/, /t/, and /k/ are manifested by the voiced allophones [b], [d], and [g], respectively. In word final position only /p/, /t/, and /k/ occur. In this position they are unreleased.

In our earlier publication[2] we dealt with the acoustic features associated with the differentiation of stop consonants in the dimension of place of articulation. Also, to a somewhat lesser extent, we dealt with those acoustic features associated with the manner differentiation of Korean stops, in particular, the differentiation of aspirated and weak stops in terms of voice onset time and the differentiation of weak and strong stops in terms of amplitude rise time. In the time since the previous report was published more data has been gathered on the voice onset time associated with weak and strong stops, and new information has been obtained on the acoustic quality of voice onset. Furthermore, a set of speech synthesis experiments were devised in order to ascertain the significance of the observed acoustics features as cues for the phonemic

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stops by various other names, such as lenis and fortis or lax and tense, respectively. In our earlier report on Korean stop consonants we used the terms lenis and fortis.

[2]See Mieko S. Han and Raymond S. Weitzman, Studies in the Phonology of Asian Languages III: Acoustic Characteristics of Korean Stop Consonants. Acoustic Phonetics Research Laboratory, University of Southern California, April, 1965.

differentiation of the stop consonants. This present report deals with these studies of our continuing investigation into the manner differentiation of Korean stop consonants and summarizes our findings to date.

ACOUSTIC FEATURES

On the wide band spectrograms, aspirated, weak, and strong stops followed by a vowel appear as shown in Figure 1, 2, and 3. Figure 1 illustrates some of the differences among [p^h], [p], and [P] when followed by the vowel [a]; Figure 2 illustrates some of the differences among [t^h], [t], and [T] followed by [a]; and Figure 3, [k^h], [k], and [K] in the same environment. These spectrograms, made from recordings of Informant 1, are typical of such utterances. In comparing the spectrograms of aspirated, weak, and strong stops with the same place of articulations and followed by a vowel, a number of differences can be noted. Generally, the differences fall under the following areas: 1) the timing of the voice onset and 2) the quality of the voice onset.

The Timing of Voice Onset

The timing of the voice onset[3] is defined as the time interval between the release of the stop and the onset of voicing as evidence by the appearance of a "voicing bar" on wide-band spectrograms. If the stop release occurs before the

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[3]In our earlier report dealing with Korean stop consonants, the timing of voice onset was referred to as the duration of aspiration.

Figure 1

Wide Band Spectrograms

Informant 1

[p^ha] [pa] [Pa]

Figure 2

Wide Band Spectrograms

Informant 1

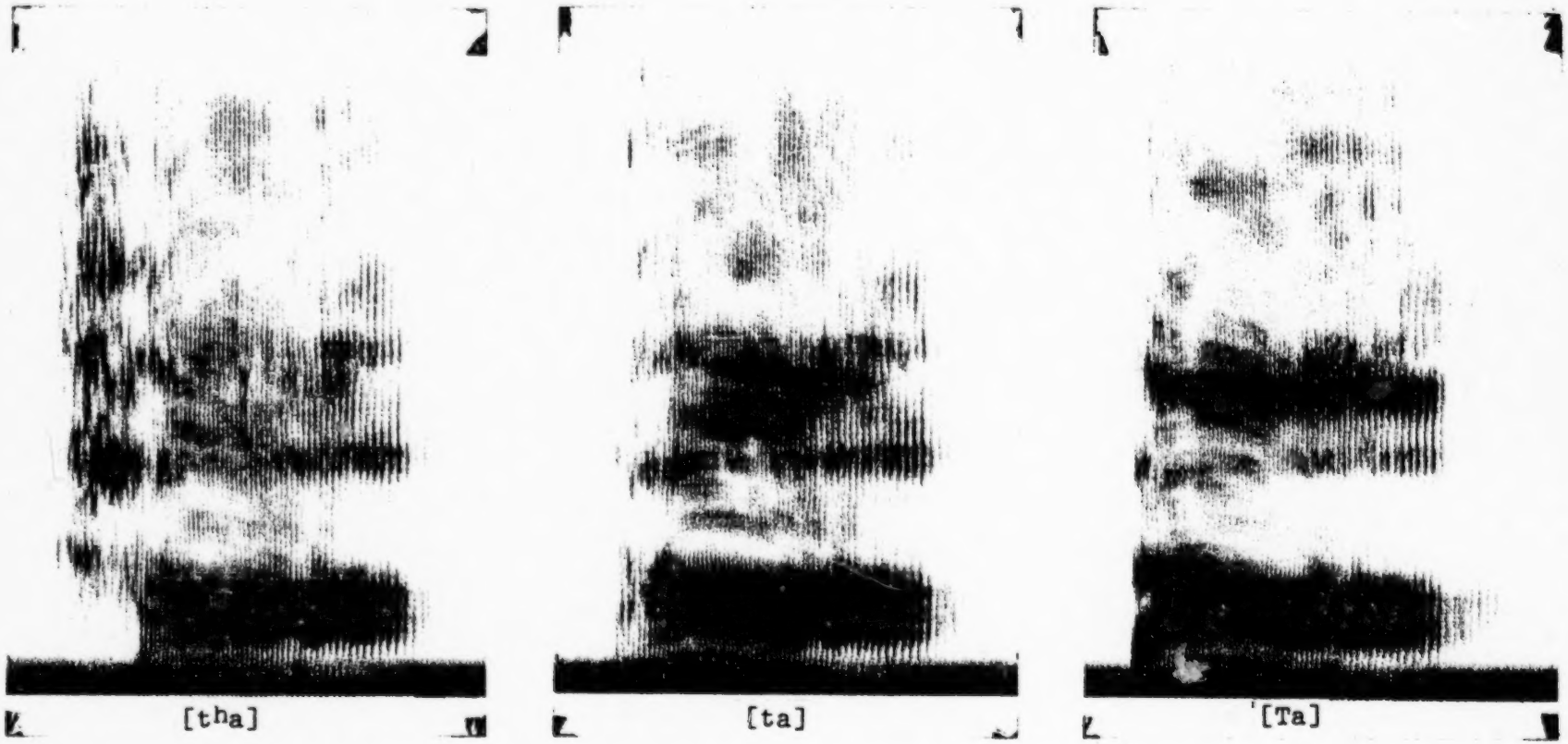
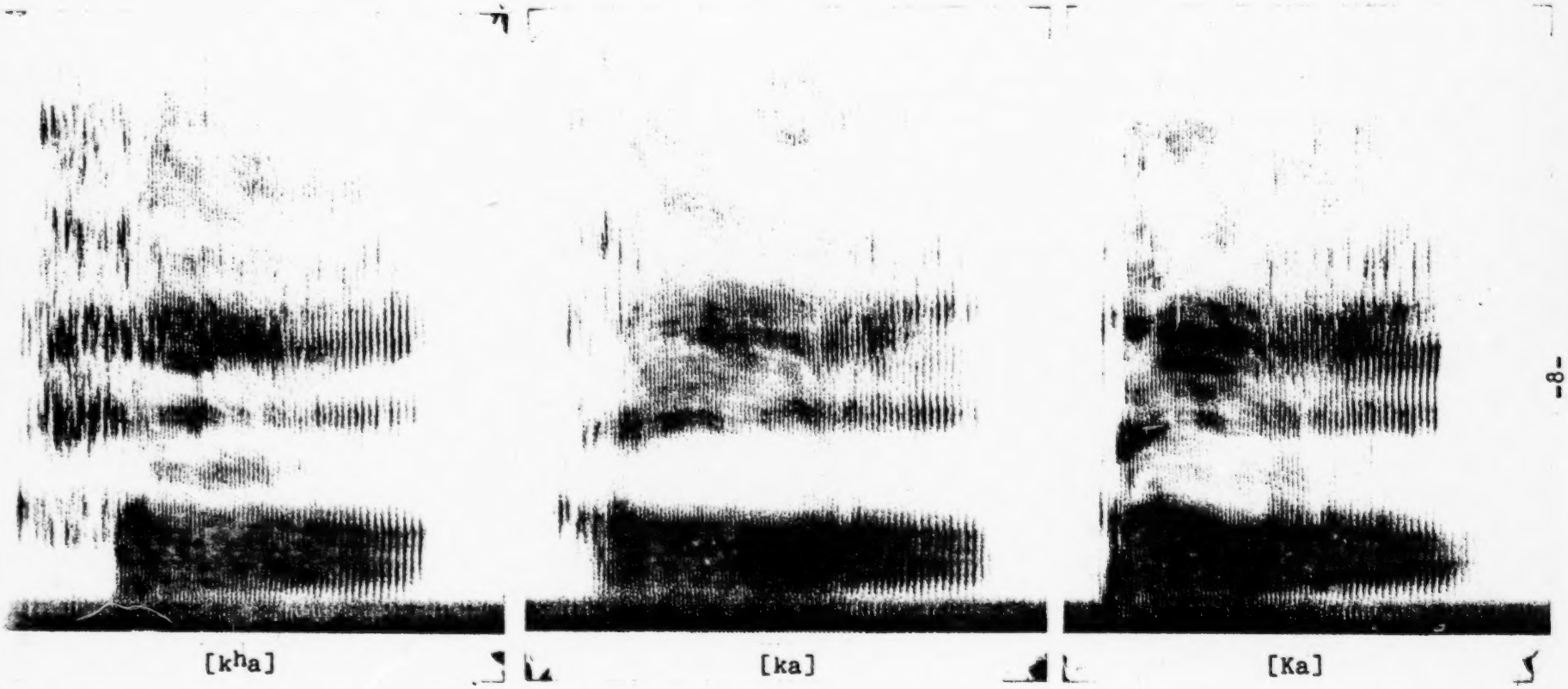


Figure 3

Wide Band Spectrograms

Informant 1



onset of voicing, voicing is said to lag the stop release; and if the stop release occurs after the onset of voicing, voicing is said to lead the stop release. In these terms then, a voiceless stop consonant is one in which voicing lags the stop release, and a voiced stop consonant is one in which voicing leads the stop release.

In order to determine the timing of the voice onset associated with aspirated, weak, and strong stops in initial position, a number of utterances were recorded by two male (Informants 1 and 2) and one female (Informant 3) speaker of the Seoul dialect of Korean.[4] Wide-band spectrograms were made of these utterances and the timing of the voice onset of the initial stop consonant in each utterance was measured. These measurements are presented in Tables 1, 2, and 3. Table 1 presents the data on voice onset time obtained from the recordings of Informant 1; Table 2 presents the data obtained from the recordings of Informant 2; and Table 3 presents the data obtained from the recordings of Informant 3.

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[4] Informant 1: S. W. Lee, male, age 29 (Informant 2 in our earlier work).

Informant 2: Y. W. Han, male, age 33 (Informant 4 in our earlier work).

Informant 3: O. K. Minn, female, age 24 (also Informant 3 in our earlier work).

TABLE 1

Voice Onset Time
(centiseconds)

Informant 1

[pʰ]*

	Rec.1		Rec.1
pʰin	9.50	pʰal	16.00
pʰil	14.50	pʰan	14.50
pʰiŋ	11.00	pʰaɔp	14.00
pʰia	17.50	pʰail	18.50
pʰi	13.00	pʰa	12.00
pʰiɕʰa	12.50	pʰat	13.50
pʰinda	12.50	pʰanda	12.50
pʰida	13.00	pʰada	13.00
pʰiri	12.50	pʰado	13.00
pʰibu	11.50	pʰaraŋ	13.00
pʰihada	12.50	pʰari	10.00
pʰinan	13.00	pʰamun	10.50
pʰiuda	13.00	pʰasan	12.00
pʰiim	14.00	pʰahan	11.50
pʰiano	15.00	pʰaak	16.50
pʰen	12.00	pʰaɔp	16.50
pʰeɔ	11.50	pʰɔnɛda	15.00
pʰe	13.00	pʰɔbutTa	12.50
pʰeiǰi	12.50	pʰo	17.50
pʰɛ	13.50	pʰokSak	11.00
pʰɛga	13.00	pʰokSok	11.00
pʰɛda	18.00	pʰogu	11.50
pʰɛmul	10.00	pʰogun	11.00
pʰɛbɛ	12.50	pʰou	12.00
pʰɛSup	11.00	pʰul	11.50
pʰɛǰɔn	10.50	pʰulPuri	8.00
pʰɛunhad	15.00	pʰuŋu	11.00
pʰɛun	11.00	pʰurogrɛm	10.50
		pʰesenthu	14.50

Average: 12.90

[tʰ]*

	Rec.2		Rec.1
tʰi	13.00	tʰɔp	12.00
tʰip	12.00	tʰɔŋ	13.50
tʰiKal	10.00	tʰok	14.00
tʰenthʰ(u)	8.50	tʰon	11.00
tʰe	16.50	tʰo	16.00
tʰɛŋǰa	13.50	tʰoŋgam	12.50
tʰɛ	13.50	tʰoŋn	15.50
tʰɛdo	14.00	tʰoŋǩin	13.50
tʰɛgo	15.00	tʰoŋhap	12.50
tʰɛsan	11.00	tʰou	12.50
tʰɛja	14.00	tʰoǰi	14.00
tʰakKu	10.50	tʰoKi	12.50
tʰangwaŋ	13.50	tʰoros	12.00
tʰa	14.00	tʰohada	17.00
tʰap	17.50	tʰosok	11.30
tʰat	15.00	tʰoo	13.80
tʰam	16.00	tʰuk	13.00
tʰak	15.50	tʰu	11.00
tʰaŋ	14.50	tʰuŋgida	8.50
tʰal	16.00	tʰusa	12.30
tʰansɛŋ	12.00	tʰuǰa	12.20
tʰalTaŋ	14.00	tʰuu	13.50
tʰalSak	12.50	tʰukKwon	11.50
tʰamdok	16.00	tʰukTe	8.50
tʰamǰɔŋ	14.00	tʰuŋmɛ	15.50
tʰaŋyak	12.00	tʰukPo	10.00
tʰaguk	14.50	tʰukSa	8.50
tʰada	15.00	tʰullida	16.00
tʰasan	12.00	tʰul	14.00
tʰain	19.00	tʰum	16.00
tʰaǰida	13.80	tʰuǰip	12.00
tʰol	13.50	tʰugi	13.50
tʰoǰɔn	13.50	tʰuda	15.00
tʰolda	13.40	tʰɯtta	12.50
tʰolǩil	11.50	tʰɯbo	13.50
tʰolbo	11.50	tʰɯro	16.50
tʰɔpSuruk	11.50	tʰügida	12.00

Average: 13.30

[kʰ]*

	Rec.1		Rec.1
kʰi	14.80	kʰɔmkʰɔmhada	12.50
kʰiuda	14.50	kʰɔɔthen	9.50
kʰeikʰu	13.50	kʰo	16.00
kʰɛndi	12.50	kʰoŋ	20.00
kʰɛmpʰu	10.50	kʰul	18.00
kʰɛda	15.00	kʰuŋ	20.50
kʰalǩʰum	13.30	kʰullɔŋgɔrida	11.90
kʰairo	12.80	kʰun	20.50
kʰɔŋ	18.30	kʰumǰikhada	11.50
		kʰüin	14.80

Average: 14.80

[k]*

ki	7.50	kok	4.50
kil	7.50	kom	5.50
kim	7.00	koŋ	5.00
kit	6.00	kol	5.00
kin	9.00	kokSɔn	5.00
kimmil	6.00	kolmok	6.00
kilToŋmu	6.50	kopTa	5.00
kimǰa	6.00	koŋgwp	4.00
kige	7.00	koŋbu	4.00
kidɛ	9.00	koɔ	5.00
kia	8.50	koǰip	7.50
kiu	7.50	koa	6.00
kii	9.00	koǰɔn	5.50
ke	4.50	ku	7.00
kegup	6.00	kuk	7.00
kesan	5.50	kun	6.50
kɛ	5.00	kuŋ	7.00
kɛk	4.50	kul	8.00
kɛkǩi	4.50	kukKi	7.00
kɛŋsɛŋ	4.00	kuŋmin	6.00
kɛbaŋ	6.00	kunPɔp	6.00
kɛsɔŋ	6.50	kunǰuŋ	7.00
kɛi	6.50	kulTuk	6.50
ka	7.50	kumTa	7.00
kap	4.50	kudu	10.00
kat	6.00	kurum	8.50
kam	4.50	kuɔ	7.50
kan	4.50	kuu	5.50
kaŋ	8.00	ku	6.00
kakKuk	5.00	kuk	5.50
kandan	6.50	kul	6.00
kalda	5.00	kum	8.50
kangak	6.00	kun	5.50
kapPu	8.50	kukTan	8.00
kaŋsup	6.00	kundɛ	6.00
karu	9.00	kumdan	5.50
kaši	9.00	kuŋǰɔŋ	5.50
kaü	7.50	kurim	7.50
kɔp	4.50	kumul	6.50
kɔt	6.50	kuɛ	7.00
kɔm	4.50	koŋgaŋ	4.00
kɔpʰum	6.50	kɛŋǰaŋ	4.50
kɔkčɔŋ	5.00	kɛmul	6.00
kɔllida	6.00	kɛsaŋ	7.00
kɔǰu	6.00	kɛi	6.50
kɔü	7.00	küsin	5.50
ko	6.00	küguk	5.00
kot	6.00	kü	8.00

Average: 6.20

[p]*

	Rec.1	Rec.2		Rec.1	Rec.2
pi	3.00	2.50	pɔt	2.00	2.00
pin	2.00	2.00	pan	2.50	2.00
pit	2.00	2.50	pɔpTa	3.00	2.00
piŋ	2.00	2.50	pɔtKot	3.00	2.00
pitČida	3.50	5.00	pɔpSɔk	4.00	3.00
pimmin	1.50	2.00	polSɔ	3.00	3.00
pimbu	3.00	2.00	po	2.00	3.00
pinsa	2.00	2.00	pok	3.00	2.50
pilda	1.50	2.50	pom	3.50	2.50
pillida	2.50	3.00	pon	3.00	2.00
pitTa	3.00	3.00	poŋ	2.50	2.00
pinǰa	2.50	2.50	pol	2.50	2.00
pɛ	2.00	2.00	pokSuŋa	3.00	2.00
pɛ	1.50	2.00	pokČoŋ	2.00	2.00
pɛk	1.50	1.50	ponguk	3.00	3.00
pɛm	1.50	1.00	ponnuŋ	3.00	3.50
pɛkČu	3.00	2.00	ponsɔŋ	4.00	3.00
pɛnda	2.50	2.00	polmo	2.50	3.00
pɛtTa	2.50	2.50	poŋsa	3.00	2.50
pɛŋman	2.00	1.50	pu	3.00	3.00
pɛŋnal	1.50	1.50	pul	3.00	2.50
pa	2.50	1.50	puk	3.00	3.50
pap	1.50	1.50	pun	4.00	3.50
pat	2.50	2.50	pulʰansɔŋ	4.50	3.50
pak	2.50	4.00	pukǰuk	2.00	3.00
pam	1.50	1.50	pukČok	3.00	3.50
pan	2.50	2.00	punsan	4.00	3.50
paŋ	1.50	3.50	punno	3.00	4.00
pal	2.00	3.00	puŋgɛ	3.00	3.50
panǩʰan	2.50	3.00	pulda	3.50	4.00
patTa	2.00	1.50	pulganuŋ	4.00	3.50
pakTa	2.00	2.00	pulKun	3.50	3.50
panǰi	2.00	1.50	pulToŋ	3.50	3.50
palSan	4.50	4.50	pullansɔ	3.50	4.00
pɔp	3.50	3.00	pulman	3.50	4.00
pom	2.00	2.00	pulPɔp	4.00	4.50
pol	2.00	2.00	pulSaŋ	2.50	4.50
polda	3.00	1.50	pulhɛŋ	4.50	4.50
			puŋdɛ	2.50	3.50

Average: 2.70

[t]*

tɛ	2.50	tɔpTa	2.50
tɛk	3.00	tɔŋɔri	2.00
tɛŋgi	2.00	tɔdida	2.00
tɛgaŋ	1.50	tɔü	2.50
tɛmun	2.50	tol	3.50
tɛsa	2.50	ton	3.00
tɛǰaŋ	2.50	tok	2.50
tɛhak	2.50	toŋgap	1.50
tɛu	2.50	tokSuri	2.50
ta	4.50	tokČu	1.50
tak	2.50	tolda	2.50
tal	4.00	togu	2.00
tam	6.00	toKi	2.00
tathuda	4.00	torio	2.50
taŋ	3.50	tu	4.00
takTa	2.50	tul	4.00
taŋgol	5.50	tutʰoŋ	8.00
talda	5.00	tuŋgulda	3.50
taŋgida	2.00	tunhada	7.50
talkida	6.50	tunɛ	5.00
taramǰü	5.50	turumagi	3.00
tɔ	3.00	tuk	4.00
tɔk	2.00	tuŋ	3.50
tɔl	3.00	tul	3.50
tɔm	3.00	tɔrɔpTa	2.00
tɔkPun	2.00	tɯnsɔri	3.50
tɔlda	2.50	tü	6.00
		tütToŋsan	3.50

Average: 3.30

[K]

Kɛ	1.50	KoŋǰI	2.00
Kø	2.00	KoŋČho	1.50
Kik	2.00	KɔkTa	1.75
Kɛŋ	1.75	KɔpČil	1.50
Køm	2.50	kida	2.75
Kul	2.25	Kɛda	2.00
Kut	2.50	KɛKuthan	1.50
Kum	3.25	Køda	2.00
Kul	2.25	Kuda	2.25
Kuk	2.75	Kada	1.50
Kok	2.25	Kaman	1.00
Kol	2.00	Kurida	3.00
Kot	2.50	Kuda	3.25
Kom	2.00	Koda	2.75
KtkKtk	1.25	Kori	1.50
Kulda	2.75	Kɔnɛda	1.50
KutKuŋmɛ	2.25	Kɔrida	2.00
KakTa	1.25	Kɛim	1.25
KalKumhada	1.50	Kɛuda	1.75
Kullida	2.25	Køida	2.00
KumKuda	3.50	Koida	1.50
KopTa	1.25		

Average: 2.04

[P]

	Rec.1	Rec.2		Rec.1	Rec.2
Pa	1.00	0.50	Palgam	0.50	0.50
Pak	0.25	0.00	Palda	0.25	0.75
Paŋ	0.50	0.75	PulPuri	0.75	1.00
Pul	1.00	1.25	Pɛnɛda	0.25	0.50
Pol	0.50	0.75	Pida	0.50	0.25
Pinda	0.50	0.00	Paǰida	0.50	0.50
PinPoŋ	0.00	0.00	Parun	0.00	0.75
Pɛnda	0.50	0.50	Puri	1.50	0.75
PɛtTa	0.50	0.00	Pøgida	0.50	0.50
Pɛŋsoni	0.25	0.50	Pio	0.50	---
PelPel	0.75	0.75	Poi	1.25	---
			PɛatTa	0.00	---

Average: 0.53

[T]

Ti	1.75	Tal	1.00
Tɛ	1.00	Tok	1.00
Te	1.25	Tɔk	0.50
Tu	1.25	Tumhada	1.00
Tɔ	1.00	TaŋPadak	0.75
Tɛm	1.00	Tultha	1.00
TÜm	2.50	TÜmbakčil	2.00
Tom	1.25	Tolda	1.25
Tul	0.75	TÜɔgada	0.75
Tut	1.25	Toorɯda	2.00
Tam	0.75	Tɛuda	1.25
		Tiuda	1.25

Average: 1.20

*The voice onset time data for these stops are taken from our earlier report Acoustic Characteristics of Korean Stop Consonants.

TABLE 2

Voice Onset Time
(centiseconds)

Informant 2

[pʰ]*

	Rec.1	Rec.2	Rec.3
pʰi	9.00	7.50	-----
pʰi	9.50	7.50	-----
pʰinda	12.00	9.50	-----
pʰinda	11.50	9.50	-----
pʰi	11.50	7.50	8.00
pʰe	13.00	11.50	12.00
pʰe	13.50	11.50	11.50
pʰe	12.50	10.00	-----
pʰe	11.50	10.00	11.00
pʰɛ	13.00	10.50	-----
pʰa	12.00	12.00	9.50
pʰa	11.50	10.50	9.50
pʰal	12.00	12.50	-----
pʰa	12.00	14.00	12.00
pʰal	11.00	12.00	-----
pʰo	9.00	9.50	9.50
pʰo	10.00	10.50	10.00
pʰok	11.00	10.00	-----
pʰo	10.50	8.50	8.50
pʰok	11.50	10.50	-----
pʰu	10.00	12.00	9.50
pʰu	11.00	12.00	9.50
pʰul	11.00	10.50	-----
pʰul	11.00	11.00	-----
pʰu	10.50	9.00	9.00
pʰolpʰol	10.00	10.00	-----
pʰolpʰol	9.00	8.50	-----

Average: 10.50

[tʰ]*

	Rec.1	Rec.2	Rec.3
tʰi	8.00	7.00	12.00
tʰi	8.00	7.00	12.00
tʰi	11.00	11.00	-----
tʰi	12.00	10.50	-----
tʰi	9.00	7.50	11.00
tʰe	9.00	9.50	-----
tʰe	9.50	10.00	-----
tʰe	11.00	9.00	-----
tʰe	11.50	9.00	-----
tʰe	17.00	15.00	-----
tʰe	12.00	8.50	12.00
tʰɛ	13.00	9.50	-----
tʰɛ	11.50	10.50	-----
tʰɛ	11.50	10.50	-----
tʰa	12.50	12.00	11.00
tʰa	12.50	11.50	11.00
tʰal	13.00	12.00	-----
tʰal	13.50	11.50	-----
tʰa	13.00	11.50	10.50
tʰo	13.50	13.00	-----
tʰo	13.50	13.00	-----
tʰo	10.00	10.00	-----
tʰo	10.00	10.00	-----
tʰo	10.00	7.50	11.00
tʰu	11.00	11.00	-----
tʰu	11.00	11.00	-----
tʰu	8.50	8.00	8.50
tʰu	8.00	8.00	7.50
tʰu	9.00	11.50	10.50
tʰolda	11.50	11.00	-----
tʰolda	11.00	11.50	-----

Average: 10.70

[kʰ]*

	Rec.1	Rec.2	Rec.3
kʰi	15.00	15.00	16.00
kʰi	15.00	15.50	15.00
kʰi	14.50	12.50	-----
kʰi	16.50	13.00	-----
kʰe	14.00	13.00	12.00
kʰe	15.00	12.00	-----
kʰe	15.00	11.50	-----
kʰɛ	16.00	17.50	-----
kʰɛda	14.00	15.00	-----
kʰɛda	14.00	15.00	-----
kʰa	13.00	12.00	12.00
kʰa	13.00	14.00	13.00
kʰal	14.50	13.00	-----
kʰal	14.00	13.00	-----
kʰa	13.00	15.50	11.50
kʰo	13.00	15.00	-----
kʰo	12.00	14.00	-----
kʰo	13.00	13.00	-----
kʰo	13.00	13.00	-----
kʰo	11.50	13.50	11.00
kʰu	13.00	13.00	-----
kʰu	13.00	13.00	-----
kʰu	11.50	11.00	-----

Average: 13.60

[p]

	Rec.1	Rec.2	Rec.3	Rec.4	Rec.5
pakʰɯ	2.50	2.00	----	----	----
pul	2.25	4.00	----	----	----
pal	1.25	1.50	1.75	----	----
pe	1.50	1.00	2.25	2.25	2.00
pa	0.75	1.50	1.00	----	----
pu	2.00	5.00	2.00	----	----
pi	1.50	2.50	----	----	----
pok	2.25	1.75	----	----	----
pinda	2.75	2.00	----	----	----
pɛ	1.25	1.75	----	----	----
po	1.50	2.00	2.00	----	----

Average: 1.96

[t]

	Rec.1	Rec.2	Rec.3
ta	3.00	3.00	1.75
tu	1.75	2.25	2.25
to	1.25	3.00	-----
te	1.25	2.25	2.50
tol	2.25	2.50	-----
tinda	3.25	3.50	-----
tal	2.00	2.00	1.75
tolda	2.00	3.00	-----
tɛ	2.50	2.50	-----
ti	1.75	2.00	2.00

Average: 2.29

[k]

	Rec.1	Rec.2	Rec.3	Rec.4
ka	6.00	5.75	5.00	----
ke	4.25	3.25	----	----
ki	4.00	6.00	4.00	4.75
ku	6.25	5.25	5.00	4.50
ko	7.25	4.50	----	----
kanda	4.00	4.75	----	----
kot	3.00	3.00	1.50	1.75
kɛ	3.00	3.00	----	----
kalkʰɯ	3.25	3.00	----	----

Average: 4.24

[P]

	Rec.1	Rec.2	Rec.3
Pi	0.50	0.50	0.50
Pa	0.50	0.50	0.50
Palda	0.50	0.50	----
Poŋ	0.00	0.50	----
PolPol	0.50	----	----
Po	0.75	1.00	0.75
Pu	1.00	0.75	0.50
Pɛ	0.25	0.25	----
Pe	0.00	0.25	0.50
Pul	0.00	0.50	----
Pinda	0.50	0.50	----

Average: 0.48

[T]

	Rec.1	Rec.2	Rec.3	Rec.4
Tu	1.00	0.50	1.00	1.00
Ta	0.25	0.50	0.75	----
Tolda	0.25	0.25	----	----
Tinda	1.00	1.00	----	----
Tɛ	0.75	0.25	----	----
Tal	0.75	1.00	----	----
Te	1.00	0.75	0.50	0.50
To	0.25	0.25	0.25	0.25
Ti	2.00	2.00	1.50	----

Average: 0.75

[K]

	Rec.1	Rec.2	Rec.3	Rec.4
Ka	1.50	2.00	----	----
Ku	3.00	3.00	----	----
Ko	4.25	3.00	----	----
Ke	1.25	1.00	----	----
Ki	3.50	3.50	5.25	3.50
Kul	2.75	2.50	----	----
Kɛ	2.50	1.50	----	----
Kanda	2.00	2.75	----	----

Average: 2.71

*The voice onset time data for these stops are taken from our earlier report Acoustic Characteristics of Korean Stop Consonants.

TABLE 3

Voice Onset Time
(centiseconds)

Informant 3

[pʰ]*

	Rec.1	Rec.2		Rec.1	Rec.2
pʰim	6.00	5.00	pʰan	8.00	5.50
pʰi	9.50	7.50	pʰaɔp	7.00	7.50
pʰičʰa	5.50	7.50	pʰail	8.50	7.00
pʰinda	6.00	6.50	pʰa	7.00	7.00
pʰida	7.50	7.50	pʰat	7.50	7.50
pʰiri	6.50	7.50	pʰanda	7.50	7.50
pʰibu	7.00	8.50	pʰada	7.50	7.50
pʰihada	7.50	8.50	pʰado	7.00	7.00
pʰinan	7.00	8.00	pʰaraŋ	9.00	8.00
pʰiuda	9.50	9.50	pʰari	9.00	8.00
pʰiim	6.50	7.50	pʰamun	7.00	4.00
pʰiano	8.50	9.00	pʰahon	6.50	7.00
pʰe	7.50	7.50	pʰaak	6.00	5.50
pʰen	5.50	4.00	pʰaɔp	7.00	6.00
pʰeiǰi	5.00	3.50	pʰasan	6.50	4.00
pʰem	6.50	7.00	pʰonɛda	7.50	6.50
pʰɛ	5.50	8.00	pʰɔbutTa	5.00	4.00
pʰɛnda	5.50	7.00	pʰokSak	8.50	5.50
pʰɛga	4.50	6.00	pʰo	7.00	6.50
pʰɛda	6.50	7.50	pʰogu	5.00	5.00
pʰɛmul	7.50	5.50	pʰogum	4.50	4.00
pʰɛbt	8.50	6.00	pʰou	2.00	3.00
pʰɛSwp	8.00	6.50	pʰulPuri	4.00	3.50
pʰeǰɔn	7.00	7.50	pʰul	7.50	8.00
pʰɛwnhada	5.00	6.00	pʰuŋu	6.50	6.50
pʰɛun	7.00	4.00	pʰurogrɛm	6.00	6.50
pʰal	9.00	6.50	pʰesentʰu	3.00	2.00

Average: 6.60

[tʰ]*

	Rec.1	Rec.2		Rec.1	Rec.2
tʰi	12.00	9.50	tʰa	8.50	9.00
tʰip	7.50	10.00	tʰɔk	8.00	6.00
tʰiKul	6.00	5.00	tʰɔl	7.00	7.50
tʰentʰu	6.00	6.50	tʰo	6.50	6.50
tʰɛ	9.00	8.50	tʰon	6.00	5.50
tʰɛǰa	7.50	9.00	tʰop	7.50	6.50
tʰɛgo	13.00	10.50	tʰoŋ	7.00	4.50
tʰɛsan	6.50	8.50	tʰu	9.00	8.50
tʰɛdo	9.50	7.50	tʰuk	5.50	6.00
tʰɛŋǰa	8.50	5.50	tʰum	6.00	4.50
tʰam	6.00	6.50	tʰul	7.00	7.50
tʰal	7.00	5.50	tʰukTɛ	5.00	4.00
tʰaŋ	7.00	7.00	tʰuŋmɛ	5.50	8.00
tʰan	6.50	6.00	tʰgtčʰa	7.50	5.50
tʰak	6.00	6.00	tʰčgida	7.50	10.00
tʰain	9.50	9.00			

Average: 7.30

[kʰ]*

	Rec.1	Rec.2	Rec.3
kʰi	10.00	10.00	11.00
kʰiuda	9.50	9.50	10.00
kʰɛikʰu	7.50	5.00	7.50
kʰɛmpʰu	8.50	6.00	-----
kʰɛndi	7.50	8.00	-----
kʰɛm	7.00	7.00	-----
kʰal	11.00	10.00	-----
kʰalčʰum	7.00	7.00	7.50
kʰɔp	6.50	5.50	4.00
kʰɔmkʰomhada	6.00	4.50	4.50
kʰo	7.00	7.50	8.50
kʰoŋ	8.50	6.50	4.50
kʰoŋKaru	7.50	7.50	6.50
kʰuŋ	7.50	6.50	6.50
kʰullɔŋgɔrida	6.00	6.50	7.50
kʰum	6.50	6.50	7.50
kʰumǰikhada	5.50	4.50	-----
kʰungil	5.00	8.00	-----
kʰūin	7.00	5.00	7.00

Average: 7.10

[p]

	Rec.1	Rec.2		Rec.1	Rec.2
pi	1.50	1.50	pam	2.25	1.75
pe	2.50	3.00	pan	0.50	2.00
pɛ	1.25	2.25	paŋ	1.75	2.00
pa	2.00	1.50	pal	1.75	2.00
pu	3.25	1.25	put	0.75	1.75
po	2.00	1.00	puk	1.25	----
pin	1.00	0.75	pun	2.00	----
pit	1.00	1.75	pul	1.50	----
piŋ	0.75	2.00	pok	1.00	----
pɛk	2.25	2.00	pom	2.25	----
pɛm	1.75	1.75	pon	1.75	----
pem	1.00	1.00	poŋ	1.25	----
pɛl	1.25	1.00	pol	1.50	----
pap	1.75	1.75	pɔp	3.50	----
pat	1.25	1.75	pɔt	1.00	----
pak	2.00	2.00	pɔn	2.75	----

Average: 1.68

[t]

	Rec.1	Rec.2		Rec.1	Rec.2
tɔm	1.75	----	tɔlda	2.50	2.50
tɛŋgi	1.75	1.75	tɔpTa	1.50	1.50
tutTɔŋsan	2.00	2.50	tɔŋɔri	2.00	1.50
tɔŋsɛri	1.75	2.00	tɔnǰida	1.75	1.75
takTa	2.00	1.50	tidimTɔl	2.00	----
tangol	2.00	2.00	tɛgaŋ	3.00	----
talda	2.00	2.00	tɛmun	2.00	----
tambɛ	2.00	2.00	tɛsa	2.25	----
taŋgida	1.75	1.50	tɛǰaŋ	2.50	----
tallɛda	1.75	2.50	tʰhak	1.50	----
tuŋgwlda	2.75	3.00	tūʰhuk	2.00	----
tunhada	3.25	4.00	tumulda	3.75	----
toŋgap	1.75	1.50	taramǰū	2.75	----
tokSuri	1.50	2.25	tatʰuda	2.50	----
tokčʰu	1.00	1.50	tunɛ	3.50	----
tolda	1.50	1.50	turumagi	3.25	----
tɔkPun	1.75	1.75			

Average: 2.10

[k]

	Rec.1	Rec.2		Rec.1	Rec.2
ki	4.25	5.00	kap	2.00	2.00
ke	4.00	3.50	kat	3.00	2.50
kɛ	3.00	3.25	kam	2.50	2.25
kŭ	4.00	4.00	kan	2.00	3.00
ku	3.00	2.50	kaŋ	2.00	2.00
ka	2.75	3.75	kuk	3.00	2.00
ku	3.25	3.00	kun	2.00	2.25
ko	3.00	2.75	kuŋ	3.00	2.00
kil	3.00	3.00	kul	2.50	2.50
kim	4.25	4.50	kot	2.50	1.75
kit	3.00	3.00	kok	2.00	2.00
kin	4.00	4.50	kom	2.00	2.00
kɛk	3.00	2.50	koŋ	2.25	2.75
kak	2.25	2.25	kol	3.00	2.00
kal	1.75	2.50	kɔp	2.50	2.50
kam	1.50	2.00	kɔt	2.25	2.25
kun	2.25	2.00	kɔn	2.00	---

Average: 2.72

[p]

	Rec.1	Rec.2		Rec.1	Rec.2
Pa	1.00	0.00	pɛlda	0.50	0.75
Pak	0.00	0.50	PulPuri	0.75	0.75
Paŋ	0.75	0.50	Pɛnɛda	0.50	0.25
Pul	1.00	0.75	Pida	0.75	0.50
pol	0.50	0.50	Paǰida	0.50	1.00
Pinda	1.00	0.50	Parun	0.50	0.75
PiŋPoŋ	0.75	0.50	Puri	0.00	0.50
Pɛnda	0.00	0.25	Pɔgida	0.50	0.00
PɛtTa	0.00	0.50	Pio	0.25	0.25
Pɛŋsoni	0.25	0.25	Poi	0.75	0.50
PɛlPɛl	0.25	0.50	PɛatTa	0.50	0.00
Palgan	0.50	0.50			

Average: 0.48

[T]

	Rec.1	Rec.2		Rec.1	Rec.2
Ti	0.50	0.50	Tuk	0.50	0.50
Te	0.25	0.25	Tok	0.25	0.50
Tɛ	1.25	1.00	Tɔk	0.25	0.25
Tu	0.50	0.75	Tumhada	1.00	0.50
To	0.50	0.75	TaŋPadak	0.25	0.25
Tam	0.25	0.50	Tultʰa	0.75	0.50
TŭM	1.50	1.00	TumbakČil	1.00	1.00
Tam	0.25	1.00	TokParo	0.50	0.50
Tal	0.00	1.00	Tɔlda	0.75	0.75
Tut	1.00	0.75	Tŭɔgada	0.75	0.75
Tam	0.25	0.25	Tɔɔmɛda	0.25	0.50
Tal	0.00	0.25	Ttuda	0.25	0.25
Taŋ	0.25	0.75	Tiuda	0.50	1.00

Average: 0.57

[K]

	Rec.1	Rec.2		Rec.1	Rec.2
Ke	1.25	1.00	KumKuda	1.00	1.75
Kø	2.00	2.25	KopTa	1.50	1.50
Kik	1.00	1.50	Koŋǰi	0.75	1.75
Kiŋ	2.75	2.00	Koŋčʰɔ	2.00	1.00
Kɛm	2.50	1.50	KɔkTa	1.00	0.75
Kal	1.25	1.50	KɔpČil	1.25	1.25
Kat	1.00	1.25	Kida	2.00	1.50
Kum	1.25	1.00	Kɛda	1.75	2.00
Kul	1.50	2.00	Kkutʰan	1.50	1.50
Kuk	1.00	1.00	Kɛda	1.75	1.50
Kok	0.25	1.50	Kuda	2.75	1.25
Kol	1.50	1.25	Kada	2.00	1.75
Kot	1.25	1.00	Kaman	1.25	1.50
Kɔm	1.00	1.00	Kurida	2.50	2.75
KɛkKɛk	1.00	1.25	Kuda	2.00	2.00
Kulda	2.00	1.75	Koda	2.50	1.50
KutKunnɛ	2.00	1.25	Kori	2.00	1.25
KakTa	0.75	1.00	Kɔnɛda	1.75	2.00
KalKumhada	2.00	2.00	Kɔrida	2.25	---
Kullida	1.50	2.25			

Average: 1.52

*The voice onset time data for these stops are taken from our earlier report Acoustic Characteristics of Korean Stop Consonants.

In Table 4 we have tabulated the average values and ranges of the voice onset time associated with each of the stops.

TABLE 4

Average Values of Voice Onset Time

(in centiseconds)

Informant 1

	Average	Range		Average	Range		Average	Range
p^h	12.90	8.00-18.50	t^h	13.30	8.50-19.00	k^h	14.80	9.50-20.50
p	2.70	1.50- 4.50	t	3.30	1.50- 8.00	k	6.20	4.00-10.00
P	0.53	0.00- 1.50	T	1.20	0.50- 2.50	K	2.04	1.25- 3.50

Informant 2

	Average	Range		Average	Range		Average	Range
p^h	10.50	7.50-14.00	t^h	10.70	7.50-17.00	k^h	13.60	11.00-17.50
p	1.96	0.75- 4.00	t	2.29	1.25- 3.00	k	4.24	1.50- 7.25
P	0.48	0.00- 1.00	T	0.75	0.25- 1.50	K	2.71	1.25- 5.25

Informant 3

	Average	Range		Average	Range		Average	Range
p^h	6.60	2.00- 9.50	t^h	7.30	4.50-13.00	k^h	7.10	4.00-11.00
p	1.68	0.50- 3.25	t	2.10	1.00- 4.00	k	2.72	1.50- 5.00
P	0.48	0.00- 1.00	T	0.57	0.25- 1.50	K	1.52	0.75- 2.75

As can been seen from this table, stop consonants having the same place of articulation are distinguished from each other by the timing of voice onset. On the average, aspirated stops have a longer interval between stop release and voice onset than weak

and strong stops, and weak stops have a longer interval between stop release and voice onset than strong stops on the average. The voice onset time of weak stops are from about 1.5 to 5 times longer than that of strong stops on the average. The voice onset time of aspirated stops are from 2.4 to 5.3 times longer than that of weak stops on the average. However, if we examine the stops in terms of their range of values, we find there is some degree of overlapping. This is particularly true between weak and strong stops. In eight out of nine cases overlapping is present. Between weak and aspirated stops the resolution is somewhat better. Overlapping occurs only in four out of nine cases.[5] Three of these cases occur in the values associated with Informant 3 between /p/ and /p^h/, /t/ and /t^h/, and /k/ and /k^h/. It is worth noting that the average values of Informant 3's aspirated stops are appreciably lower than those of the other two informants. This seems to be a personal characteristic of the speech of this informant, for in examining spectrographic samples of other female speakers, it was observed that duration of aspiration was comparable to that observed with the two male informants.

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[5]Similar observations of overlapping have been made by Leigh Lisker and Arthur S. Abramson in their article "A Cross Linguistic Study of Voicing in Initial Stops: Acoustical measurements," Word, 20, No. 3 (1964), pp. 384-422.

Quality of Voice Onset

Besides the differences observed in the timing of voice onset between aspirated, weak, and strong stops, there also occur acoustic differences in the initial phase of voicing itself. These differences are manifested in terms of (1) the onset value of the fundamental frequency of a vowel following a stop consonant and (2) intensity characteristics of the initial phase of voicing.

Fundamental Frequency--Narrow-band spectrograms of utterances beginning with a stop consonant recorded by Informants 1 and 3 were made. From these, measurements were taken of the onset value of the fundamental frequency of the vowel preceded by one of the stops. (See Tables 5 and 6). Figures 4, 5, and 6 illustrate the fundamental frequency contour of the vowel [a] preceded by one of the nine stop consonants.[6] The averages and ranges of values have been tabulated and are presented in Table 7.

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[6]These contours were made by a pitch extracting and data recording system, consisting of an adjustable filter type pitch extractor, a six channel galvanometric amplifier, and an eight channel visicorder oscillograph. The pitch extractor was built for us by the Office of Naval Research.

TABLE 5

Onset Value of Fundamental Frequency
(cycles/second)

Informant 1

[pʰ]

	Rec.1	Rec.2	Rec.3	Rec.4	Rec.5
pʰa	150	160	160	175	158
pʰi	150	175	175	200	212
pʰu	200	200	190	200	151
pʰɛ	187	150	187	200	187
pʰo	220	210	220	200	217

Average: 183

[tʰ]

	Rec.1	Rec.2	Rec.3	Rec.4	Rec.5
tʰa	200	187	190	180	185
tʰi	225	225	212	200	200
tʰu	217	217	212	200	183
tʰɛ	217	225	233	217	185
tʰo	220	220	210	190	175

Average: 205

[kʰ]

	Rec.1	Rec.2	Rec.3	Rec.4	Rec.5
kʰa	195	210	205	180	180
kʰi	212	212	212	200	187
kʰu	220	225	225	185	175
kʰɛ	200	200	212	175	208
kʰo	220	230	200	195	166

Average: 201

[p]

pa	130	137	140	140	130
pi	133	150	140	155	137
pu	150	150	150	160	170
pɛ	137	137	150	150	160
po	150	150	150	170	170

Average: 144

[t]

ta	140	150	130	150	165
ti	175	150	173	166	166
tu	162	170	170	166	170
tɛ	160	170	169	162	150
to	160	165	160	165	160

Average: 161

[k]

ka	140	165	150	140	150
ki	165	162	166	170	170
ku	170	170	166	170	166
kɛ	162	168	162	166	160
ko	170	163	170	170	160

Average: 162

[P]

Pa	145	150	160	170	175
Pi	180	175	175	215	195
Pu	175	180	170	195	200
Pɛ	170	170	170	185	195
Po	180	170	170	190	190

Average: 178

[T]

Ta	180	177	180	195	190
Ti	200	225	191	195	195
Tu	191	191	195	210	195
Tɛ	187	190	180	190	181
To	185	190	181	190	190

Average: 191

[K]

Ka	170	175	175	175	195
Ki	175	185	180	195	190
Ku	200	200	200	180	180
Kɛ	185	192	192	190	190
Ko	200	205	190	190	190

Average: 188

TABLE 6

Onset Value of Fundamental Frequency
(cycles/second)

Informant 3

[pʰ]

	Rec.1	Rec.2		Rec.1	Rec.2
pʰi	325.0	335.0	pʰinda	347.5	350.0
pʰe	327.5	317.5	pʰenda	333.0	368.7
pʰɛ	317.5	330.0	pʰanda	355.0	350.0
pʰa	320.0	350.0	pʰulda	333.3	341.6
pʰo	333.0	357.5	pʰokSak	342.5	331.2
pʰən	360.0	343.2	pʰida	335.0	---
pʰat	352.5	347.5	pʰiri	344.4	---
pʰul	347.5	347.5	pʰibu	332.5	---
			pʰihada	355.0	---

Average: 341

[tʰ]

	Rec.1	Rec.2		Rec.1	Rec.2
tʰi	322.5	342.5	tʰat	340.0	---
tʰe	312.5	322.5	tʰam	327.5	---
tʰɛ	322.5	335.0	tʰak	340.0	---
tʰa	312.5	307.5	tʰaŋ	330.0	---
tʰu	317.5	320.0	tʰal	335.0	---
tʰo	322.5	307.5	tʰuk	347.5	---
tʰip	317.5	367.5	tʰom	335.0	---
tʰul	332.5	370.0	tʰop	350.0	---
tʰum	327.5	---	tʰoŋ	350.0	---
tʰap	320.0	---	tʰok	352.5	---
			tʰol	367.5	---

Average: 334

[kʰ]

	Rec.1	Rec.2		Rec.1	Rec.2
kʰi	345.0	325.0	kʰɛndi	330.8	327.5
kʰe	333.3	327.5	kʰɛmpʰu	310.0	310.0
kʰan	350.0	350.0	kʰangili	330.0	340.0
kʰai	370.0	375.0	kʰiuda	345.0	327.5
kʰaŋ	372.5	370.0	kʰɛikʰu	330.0	345.0
kʰoŋ	350.0	350.0	kʰɛin	325.0	340.0
kʰap	387.0	387.0	kʰairo	330.0	350.0
			kʰɛtʰen	330.0	350.0

Average: 345

[p]

pɛ	270.0	272.5	pɛk	280.0	275.0
pa	255.0	258.3	pim	260.0	270.0
pu	252.5	260.0	pam	260.0	270.0
po	250.0	250.0	pal	267.5	---
pi	250.0	250.0	pap	260.0	---
pe	265.0	260.0	pat	260.0	---
pin	255.0	270.0	pak	272.5	---
pit	270.0	272.5	pam	280.0	---
piŋ	292.5	287.5	pan	260.0	---
			paŋ	275.0	---

Average: 266

[t]

tɛ	317.5	315.0	tam	315.0	---
tu	306.0	305.0	taŋ	325.0	---
tɛ	305.0	292.5	tal	306.0	---
ta	320.0	310.0	tol	307.5	---
tu	308.0	310.0	toŋ	312.5	---
to	310.0	307.5	tok	325.0	---
tuk	305.5	---	tok	327.5	---
tuk	317.5	---	tol	317.5	---
tuŋ	317.5	---	tom	307.5	---
tul	307.5	---	tik	317.5	---
tuk	306.0	---	tuk	327.5	---
tal	306.0	---	tuŋ	317.5	---

Average: 312

[k]

ki	307.5	302.5	kit	322.5	---
ke	292.5	297.5	kin	307.5	---
kɛ	297.5	316.6	kik	327.5	---
ka	297.5	302.5	kuk	322.5	---
ku	297.5	297.5	kul	317.5	---
ko	297.5	305.0	kum	317.5	---
kil	319.4	307.5	kuŋ	327.5	---
kim	307.5	---	kap	297.5	---
			kat	325.5	---
			kam	317.5	---
			kaŋ	310.0	---

Average: 309

[P]

Pa	292.5	277.5	PatTa	315.0	307.5
Pɛk	302.5	297.5	Pɛŋsoni	305.0	307.5
Paŋ	312.5	310.0	PalPal	312.5	322.5
Pul	320.0	315.0	Palgan	310.0	317.5
Pol	320.0	312.0	Palda	315.0	312.5
Pinda	305.0	305.0	PulPuri	322.5	300.0
PiŋPoŋ	307.5	305.0	Pɛnda	317.5	---
Pɛnda	302.5	310.0	Pida	302.5	---

Average: 308

[T]

Ti	345.0	337.5	Tal	345.0	360.0
Tɛ	327.5	337.5	Tut	370.0	370.0
Te	347.5	337.5	Tan	347.5	337.5
Tu	339.3	325.0	Tal	352.5	340.0
To	345.0	342.5	Taŋ	350.0	340.0
Tɛn	347.5	350.0	Tuk	350.0	357.5
Tun	335.0	327.5	Tok	365.0	---
Tun	347.5	347.5	Tok	327.5	---

Average: 345

[K]

Ki	320.0	330.0	Kun	350.0	340.0
Kɛ	320.0	330.0	Kul	350.0	355.0
Kik	335.0	345.0	Kuk	345.0	340.0
Kaŋ	325.0	320.0	Kok	350.0	330.0
Kan	330.0	330.0	Kol	355.0	350.0
Kul	330.0	350.0	Kot	350.0	350.0
Kut	340.0	355.0	Kom	330.0	330.0
			KɛKKa	320.0	330.0

Average: 337

FIGURE 4

Fundamental Frequency Contour

Informant 1

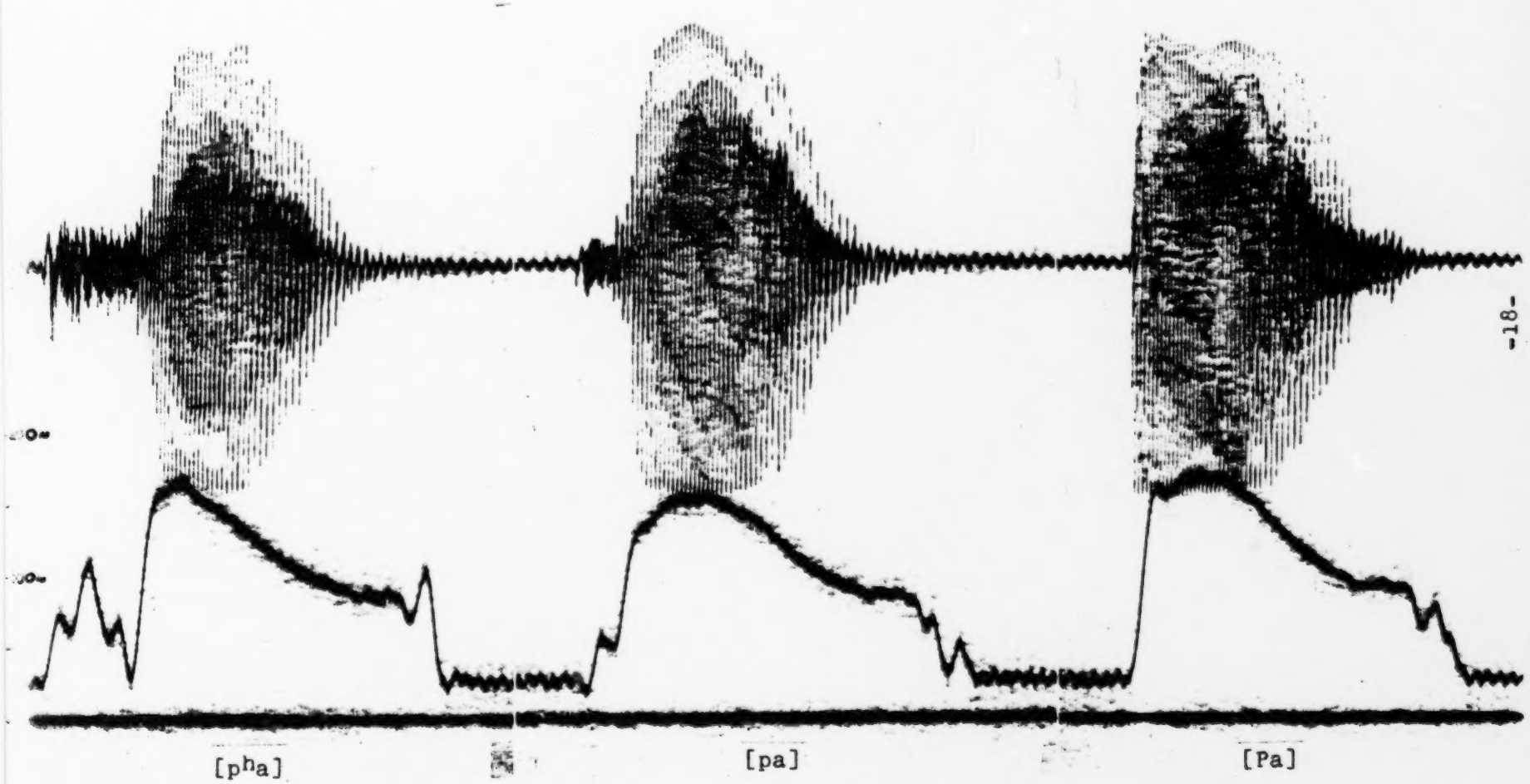

FIGURE 5

Fundamental Frequency Contour

Informant 1

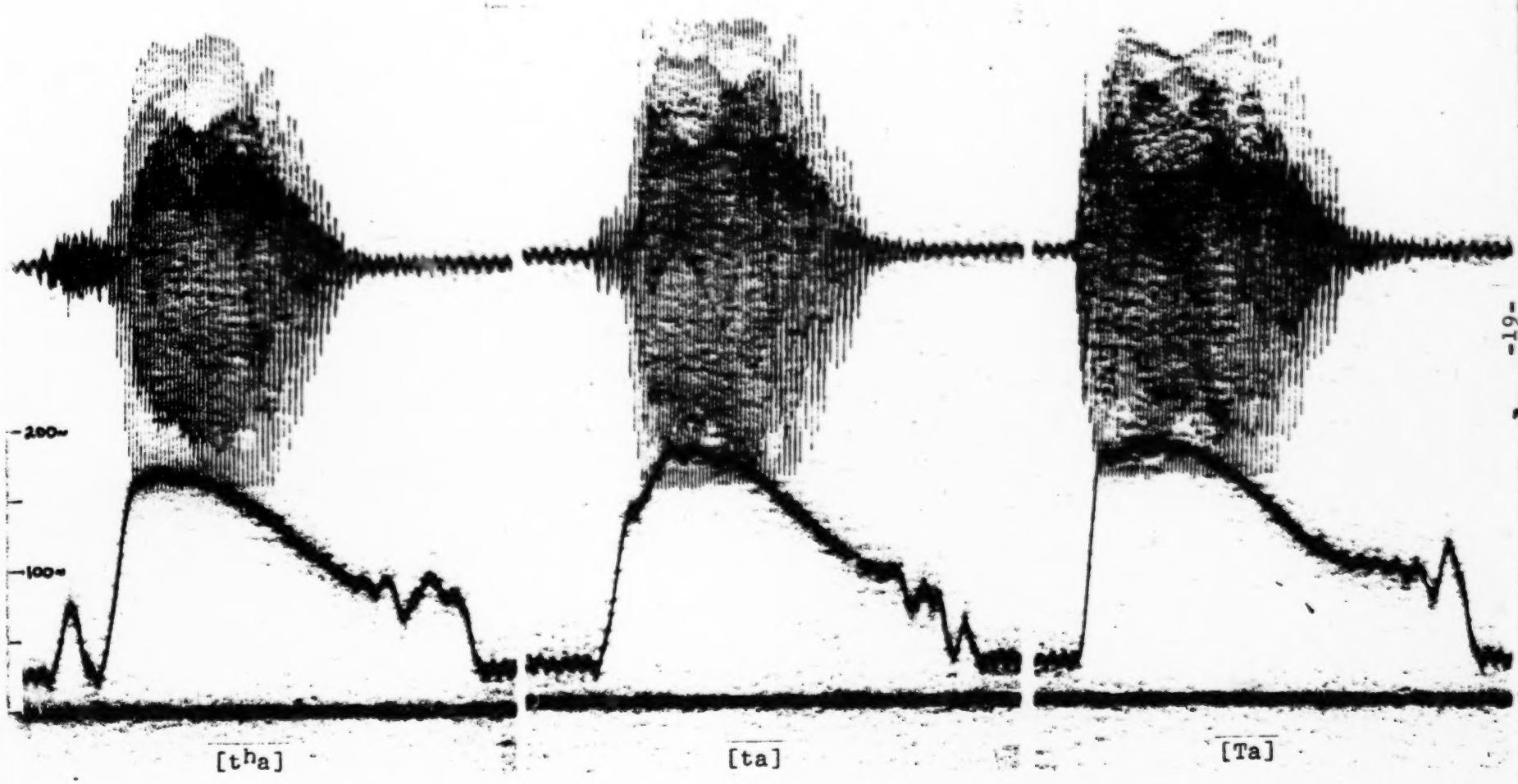

FIGURE 6

Fundamental Frequency Contour

Informant 1

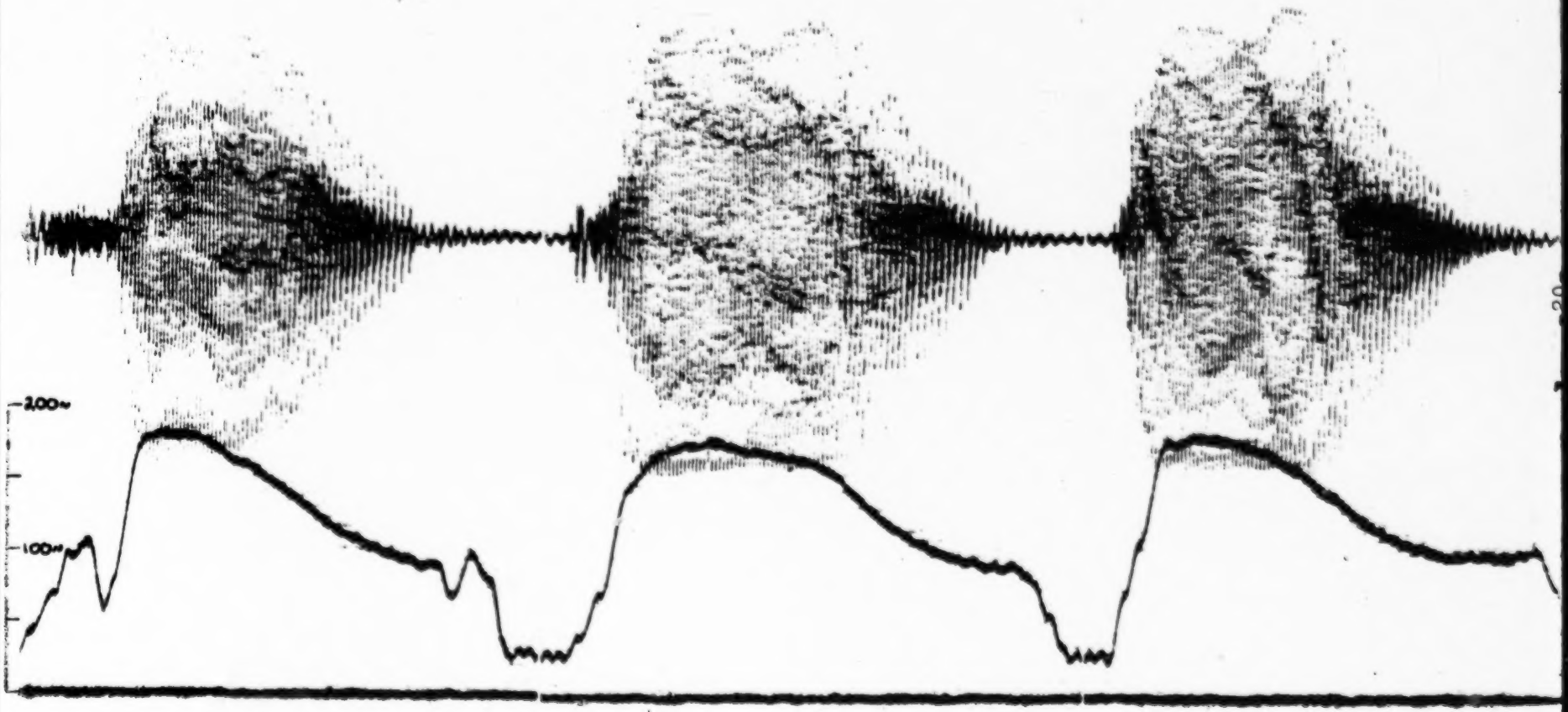

TABLE 7

Onset Values of Fundamental Frequency
Following a Stop Consonant

(cycles/second)

Informant 1

	Avg.	Range		Avg.	Range		Avg.	Range
[pʰ]	185	150.0-220.0	[tʰ]	205	175.0-233.0	[kʰ]	201	166.0-230.0
[p]	144	130.0-170.0	[t]	161	130.0-173.0	[k]	162	140.0-170.0
[P]	178	145.0-215.0	[T]	191	177.0-225.0	[K]	188	170.0-205.0

Informant 3

	Avg.	Range		Avg.	Range		Avg.	Range
[pʰ]	341	317.5-368.7	[tʰ]	334	307.5-367.5	[kʰ]	343	310.0-389.0
[p]	266	250.0-292.5	[t]	312	292.5-327.5	[k]	309	292.5-327.5
[P]	308	277.5-322.5	[T]	345	325.0-370.0	[K]	337	320.0-355.0

As can be seen from Table 7, the onset value of fundamental frequency following an aspirated or strong stop is relatively higher than that following a weak stop on the average. For example, in the case of Informant 1, the average onset value of fundamental frequency following a strong stop is between 13 and 18 percent higher than that following a weak stop, and in the case of Informant 3, the average onset value of fundamental frequency following a strong stop is between 9 and 16 percent higher than that following a weak stop. However, there is considerable overlapping of individual values as indicated by the various ranges. In some cases, as with the

bilabial stops of Informant 1 and with the velar stops of Informant 3, there is mutual overlapping between the onset values of fundamental frequency following all three stops. This extreme overlapping suggests that the onset value of fundamental frequency cannot be too significant a cue in the distinction of stop consonants.

Intensity Characteristics--It was noted in our earlier work[7] on Korean stops that in CV syllables with an initial weak stop the onset of the vowel is not very sharp, giving the vowel the appearance of being gradually formed after the stop release. This differs from the case where the initial stop is a strong one. In this case we generally find that the vowel onset is very sharp. These observations are reflected in the fact the formant transitions of a vowel following a weak stop are often obscured and relatively weak, and often there is the presence of noise mixed in with the quasi-periodicity of the vowel during its first few centiseconds of production. In contrast to this, the formant transitions of a vowel following a strong stop are clear and relatively stronger than those following a weak stop, and little or no noise is detected in the first few centiseconds of the vowel. Furthermore, we find that the higher harmonic partials at the vowel onset are relatively more dampened when preceded by a weak stop than when preceded by a strong stop. This dampening of the higher harmonic partials following a weak stop usually lasts from 2-5 centiseconds. These observations

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[7]Han and Weitzman, Op. cit., p. 150.

all point to the fact that the overall intensity of the vowel onset following a weak stop is less than that following a strong stop. In our earlier report, this was discussed in terms of amplitude rise time--i.e., in terms of the slope of the leading edge of the overall intensity curve as produced on spectrograms with the aid of the Amplitude Display accessory unit of the Kay Sona-graph. This data revealed that overall intensity rose more quickly following a strong stop than following a weak stop.

Vowel onset quality following an aspirated stop is similar to that following a weak stop, in that at times the higher harmonic partials are relatively weaker than in vowels following a strong stop, although, this weakening is often of a shorter duration than found in vowels following a weak stop, and there is the presence of noise superimposed on the quasi-periodicity of the vowel at its onset. Thus, the vowel onset quality following an aspirated stop is somewhat intermediate between that following a strong stop and that following a weak stop. Similar to vowel quality following a strong stop, the vowel onset quality following an aspirated stop sometimes has a relatively high onset value of fundamental frequency. Also similar to the vowel quality following a weak stop, it shares the features of relatively more dampened higher harmonic partials and an intermixture of noise in the first few centiseconds of the vowel. However, the feature of relatively more dampened higher harmonic partials is not consistently observed in vowels following an aspirated stop. In some cases it appears to be so negligible as to be hardly significant.

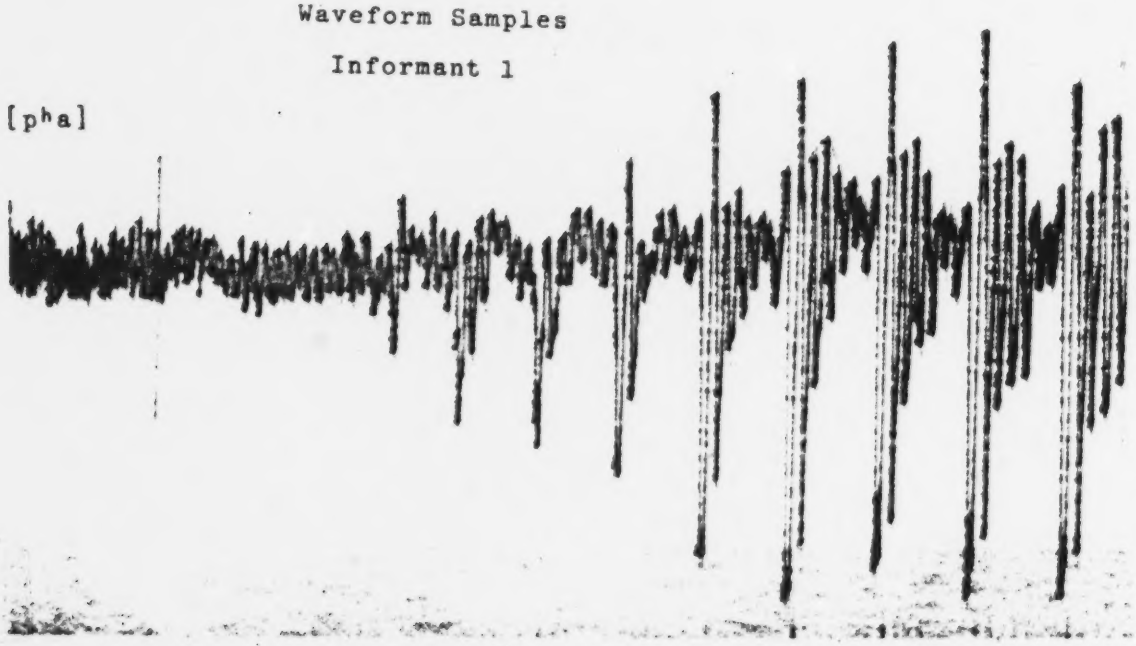
In order to gain further information on the intensity characteristics of the beginning portion of a vowel following a stop consonant, the waveform properties of these vowels were examined. Figures 7, 8, and 9 represent typical waveform patterns of the vowel [a] preceded by one of the stop consonants. The waveform patterns of tape-recorded utterances played back at half speed were recorded by the visicorder at a recording speed of 50 inches per second. The speed at which the utterances were played back and the high speed of recording by the visicorder were necessary to ensure that each period of vibration was clearly distinguished.

The most striking differences that were observed in the waveform patterns was in the build-up of amplitude over time. Following a weak stop, there is a relatively slow build-up in amplitude. In the samples of Informant 1, the duration of build-up was about 4 centiseconds on the average. Following a strong, stop the amplitude build-up was of a relatively brief duration, averaging about 0.8 centiseconds. Following an aspirated stop, the duration of amplitude build-up was about 2 centiseconds and thus somewhat intermediate between the duration of amplitude build-up following a weak stop and that following a strong stop. (See Figures 7, 8, and 9 for sample comparisons of the waveform patterns illustrating the differences in the character of voice onset.) These differences in waveform patterns correlate well with our observations with respect to amplitude rise time, where we observed that the slope of the leading edge of the intensity curve was greater

Waveform Samples

Informant 1

[pʰa]



[pa]

[Pa]

1" = 1 centisecond

FIGURE 8

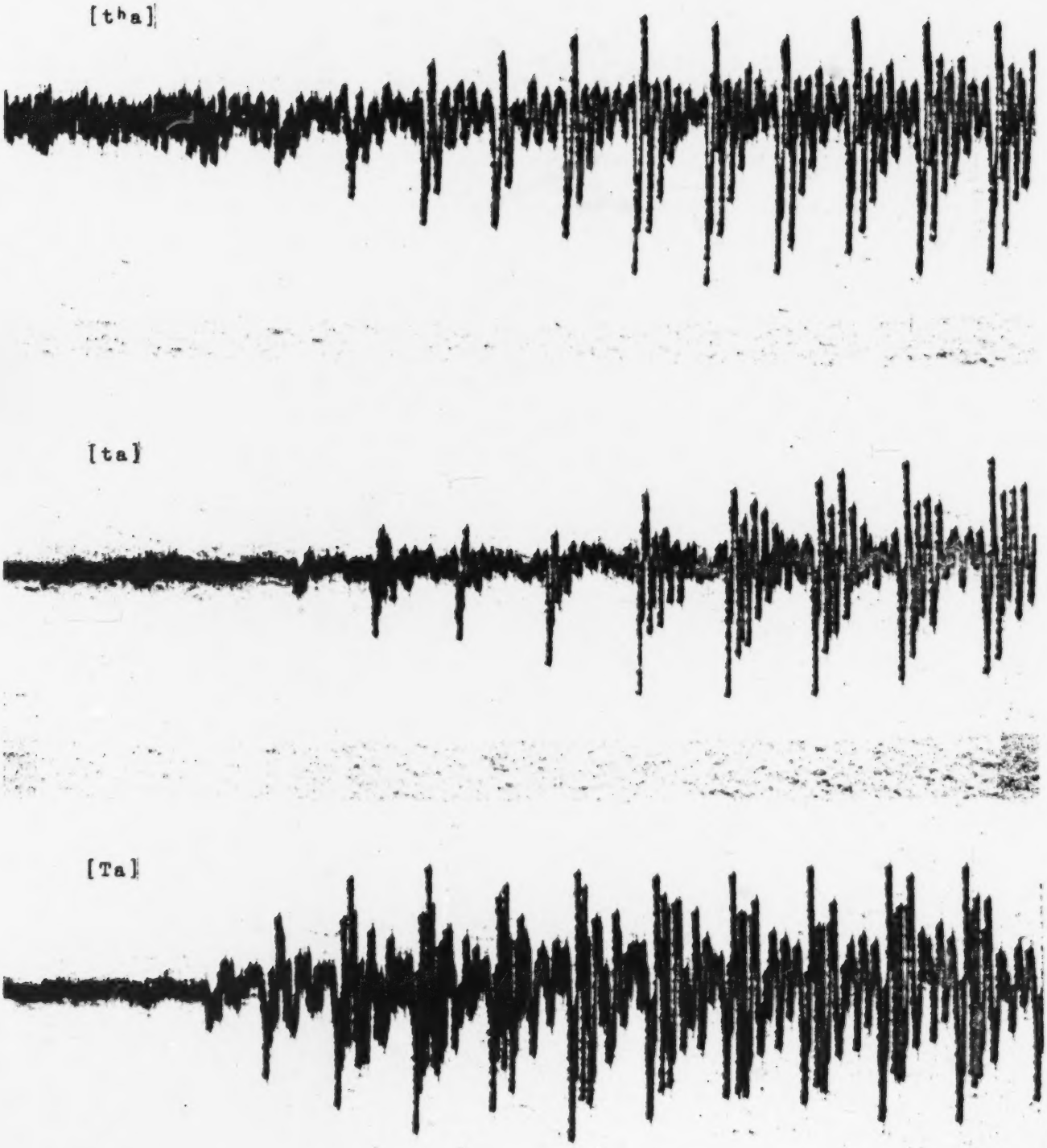
Waveform Samples

Informant 1

[tʰa]

[ta]

[Ta]



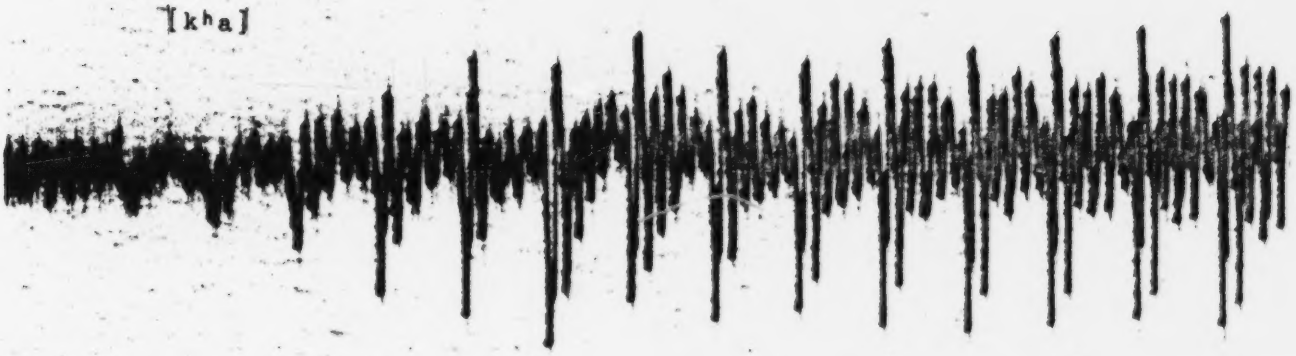
1" = 1 centisecond

FIGURE 9

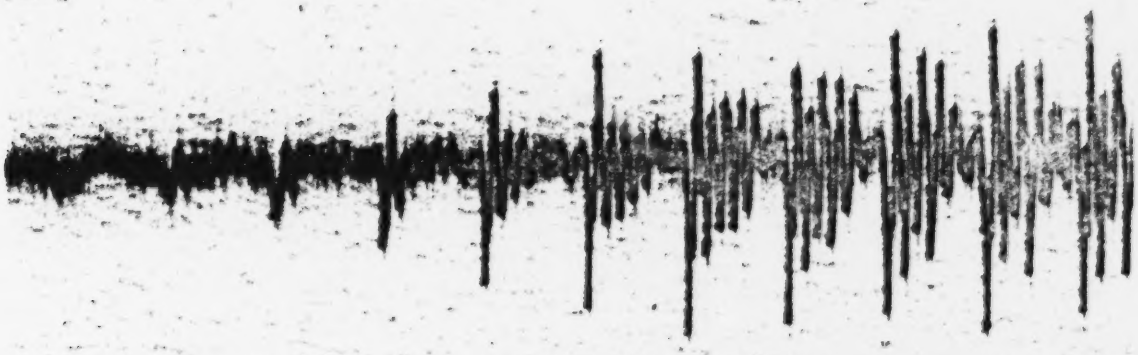
Waveform Smaples

Informant 1

[kʰa]



[ka]



[Ka]

1" = 1 centisecond

in syllables with an initial strong stop than in those with an initial weak stop. They also seem to explain why CV syllables in which the consonant is a weak stop sound soft to the ear, while CV syllables in which the consonant is a strong stop sound sharp to the ear. It was observed in some waveform samples that the peak amplitude of the first period of voicing did not appear to be substantially different whether the stop that preceded the voicing was weak, strong, or aspirated. In some cases the amplitude following a strong or aspirated stop was greater than that following a weak stop, but this difference was not consistently observed.

Summary

These differences in voice onset time and voice onset quality that have been observed, although suggestive, do not necessarily indicate that they are significant cues for the phonemic differentiation of aspirated, weak, and strong stops. At first glance it would seem that only the dimension of voice onset time is necessary for the distinction of these stops. However, as we have noted earlier a good deal of overlapping exists in this dimension, especially between the data for weak stops and strong stops. In the dimension of the onset value of fundamental frequency, the onset value associated with weak stops seems to be significantly different on the average from those following aspirated stops which, however, do not seem to be significantly different on the average from those

following a strong stop. Therefore, the significance of the feature of onset value of fundamental frequency, if any, seems to lie in distinguishing aspirated and strong stops from weak stops rather than in distinguishing all three from each other. In the dimension of intensity, our studies show that there is a gradual build-up of intensity in a vowel preceded by a weak stop, while in vowels preceded by a strong stop, the build-up in intensity is relatively more rapid. Vowels preceded by an aspirated stop sometimes show a rapid build-up in intensity and sometimes a more gradual build-up, but usually not as gradual as that found in vowels preceded by a weak stop. It seems, therefore, that the dimension of intensity is more relevant in distinguishing weak stops from strong stops.

TAPE CUTTING AND SPLICING EXPERIMENTS

Design and Procedure of the Experiments

The only positive way to determine the significance of the parameters voice onset time, onset value of fundamental frequency, and intensity in the manner-differentiation of Korean stops is to vary these values in a controlled manner and then test the native speaker's reaction to the changes. An electronic speech synthesizer is the most appropriate instrument to use in such an experiment. However, such a device was not available to us. Instead, we used the tape cutting and splicing method.[8] Through this method portions of an utterance recorded on tape can be removed and the remaining portions spliced together. The altered utterance can then be played back and the reaction of a native speaker to this utterance tested. In this way the effect of removing a given portion of the utterance on a native speaker's responses to the utterance can be determined and to that extent the significance of the removed portion and the remainder in the phonemic differentiation of sounds.

In one set of experiments syllables consisting of one of the aspirated stops followed by either [a], [i], or [u] were

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[8]We are indebted to Professor A. S. Abramson for suggesting this method of speech synthesis to us as a means of furthering our investigation.

recorded by Informant 1. Then the same token of each syllable was re-recorded several times on another tape at 15 inches per second. Wide-band spectrograms were made of each syllable to determine the time interval between stop release and voice onset. The point on the tape where the stop was released was determined by slowly drawing the tape over the reproduce head of the tape recorder and marked. The initial 1 centisecond after the stop release was retained[9] and segments within the time interval from stop release to voice onset were cut out in small steps until this time interval was completely removed (except for the initial 1 centisecond). Subsequently, portions of the voicing of the following vowel were removed in steps of about 1 centisecond for a total of about 3 centiseconds. The accuracy of the cutting was checked by spectrograms. Each reproduction of a given syllable token was cut only once. The original syllable tokens and the tokens made from cutting and splicing were each dubbed three times onto another tape in random order for the purposes of a listening test.

A listening test sheet written in Korean "Hangul" orthography (which is essentially a phonemic orthography) was prepared. (See Appendix). Only the symbols for stop consonants were printed on the test sheet. For each stimulus syllable 2 to 6 choices were listed. The listening subjects were eleven native speakers of the Seoul dialect of Korean--5 women and

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[9]This could not be done in every case due to the inherent inaccuracy of the tape cutting method.

6 men, ranging in age from 20 to 35. Following a warm-up test to familiarize the subjects with Informant 1's voice, the prepared set of stimulus syllables was played and the subjects were instructed to listen carefully and respond by circling that choice which best represented what they had heard.

The purpose of this experiment was to determine the significance of the acoustic features that had been observed in conjunction with the aspirated, weak, and strong stops. Specifically, we were interested in ascertaining the responses of the subjects as more and more aspiration and portions of voicing were removed.

Results and Discussion

The responses of the subjects are tabulated and presented in Table 8.

TABLE 8

Tape Cutting and Splicing Experiments
Responses of the Subjects

Experiment 1A. Original: [pʰa]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	13.50	0.00	11	0	0
2	2.00	11.50	0.00	11	0	0
3	4.00	9.50	0.00	11	0	0
4	5.75	7.25	0.00	11	0	0
5	7.75	5.25	0.00	10	1	0
6	10.50	3.00	0.00	4	7	0
7	12.75	0.75	0.00	0	10	1
8	12.75	0.75	2.00	0	7	4
9	12.75	0.75	3.25	0	1	10

* in centiseconds

TABLE 8 continued

Experiment 1B. Original: [t^ha]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	10.50	0.00	11	0	0
2	2.00	8.50	0.00	11	0	0
3	4.00	6.50	0.00	10	1	0
4	6.00	4.50	0.00	6	5	0
5	8.50	2.00	0.00	1	10	0
6	9.75	0.75	0.00	0	9	1
7	9.50	1.00	2.00	0	8	3
8	9.50	1.00	3.00	0	1	10

* in centiseconds

TABLE 8 continued

Experiment 1C. Original: [kʰa]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	14.00	0.00	11	0	0
2	2.00	12.00	0.00	11	0	0
3	4.00	10.00	0.00	11	0	0
4	6.00	8.00	0.00	11	0	0
5	8.00	6.00	0.00	5	6	0
6	10.50	3.50	0.00	0	11	0
7	12.50	1.50	0.00	1	10	0
8	13.00	1.00	0.50	0	5	6
9	13.00	1.00	1.75	0	5	6
10	13.00	1.00	2.50	0	1	10

* in centiseconds

TABLE 8 continued

Experiment 2A. Original: [pʰi]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	15.75	0.00	11	0	0
2	2.00	13.75	0.00	11	0	0
3	4.25	11.50	0.00	11	0	0
4	6.25	9.50	0.00	11	0	0
5	8.25	7.50	0.00	11	0	0
6	10.25	5.50	0.00	10	1	0
7	12.25	3.50	0.00	2	9	0
8	15.00	0.75	0.00	0	9	2
9	14.75	1.00	1.00	0	0	11
10	14.75	1.00	2.00	0	0	11

* in centiseconds

TABLE 8 continued

Experiment 2B. Original: [tʰi]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	10.50	0.00	11	0	0
2	2.00	8.50	0.00	11	0	0
3	4.00	6.50	0.00	10	1	0
4	6.00	4.50	0.00	8	3	0
5	8.50	2.00	0.00	2	9	0
6	9.50	1.00	0.00	0	8	3
7	9.75	0.75	1.00	0	1	10
8	9.50	1.00	2.00	0	0	11
9	9.50	1.00	3.00	0	0	11

* in centiseconds

TABLE 8 continued

Experiment 2C. Original: [kʰi]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	13.00	0.00	11	0	0
2	2.00	11.00	0.00	11	0	0
3	4.25	8.75	0.00	11	0	0
4	5.75	7.25	0.00	11	0	0
5	8.25	4.75	0.00	9	2	0
6	10.25	2.75	0.00	2	9	0
7	11.75	1.25	0.25	0	0	11
8	12.00	1.00	1.00	0	2	9
9	12.00	1.00	2.25	0	2	9
10	12.00	1.00	3.25	0	1	10

* in centiseconds

TABLE 8 continued

Experiment 3A. Original: [pʰu]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	10.75	0.00	11	0	0
2	2.75	8.00	0.00	11	0	0
3	4.25	6.50	0.00	11	0	0
4	6.50	4.25	0.00	10	1	0
5	8.50	2.25	0.00	8	3	0
6	9.75	1.00	0.00	0	9	2
7	9.75	1.00	1.00	0	6	5
8	9.75	1.00	3.00	0	0	11

* in centiseconds

TABLE 8 continued

Experiment 3B. Original: [tʰu]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	11.25	0.00	11	0	0
2	2.50	8.75	0.00	11	0	0
3	4.00	7.25	0.00	11	0	0
4	6.50	4.75	0.00	8	3	0
5	8.50	2.75	0.00	4	7	0
6	10.00	1.25	0.25	0	1	10
7	10.25	1.00	1.25	0	0	11
8	10.25	1.00	2.50	0	1	10
9	10.25	1.00	3.25	0	0	11

* in centiseconds

TABLE 8 continued

Experiment 3C. Original: [k^hu]

Description of Samples Heard				Responses of Subjects		
Token	Amount of Aspiration Removed*	Voice Onset Time*	Amount of Voicing Removed*	Heard as Asp. Stop	Heard as Weak Stop	Heard as Strong Stop
1	0.00	12.75	0.00	11	0	0
2	2.25	10.50	0.00	11	0	0
3	4.00	8.75	0.00	11	0	0
4	6.25	6.50	0.00	9	2	0
5	8.25	4.50	0.00	7	4	0
6	10.25	2.50	0.00	0	11	0
7	11.75	1.00	0.25	0	1	10
8	11.75	1.00	1.25	0	3	8
9	11.75	1.00	2.00	0	1	10
10	11.75	1.00	3.25	0	0	11

* in centiseconds

To get a better idea of the effect of the cuttings on the subjects' responses, the percentage of times the initial consonant of a given stimulus syllable was heard as either aspirated, weak, or strong was computed. These were then plotted on graph paper and are presented in Figures 10, 11, and 12. The vertical axes indicate the percentage of responses and the horizontal axes indicate the amount of aspiration and voicing which had been removed, if any, in the stimulus syllable. Where possible a smooth curve has been drawn connecting the points. These graphs give us some idea of the 50% cross-over points from aspirated to weak stop responses and from weak to strong stop responses. As can be seen from these graphs the 50% cross-over point from aspirated stop to weak stop comes after between 55 and 83 percent of the aspiration had been removed.

In four cases the 50% cross-over point from weak stop to strong stop occurred after some amount of voicing had been removed. In Figures 10a, 10b, 10c, and 12a the 50% cross-over point occurred after 2.5 centiseconds, 2.5 centiseconds, 0.25 centiseconds, and 1.25 centiseconds of voicing had been removed, respectively. In three cases the 50% cross-over point from weak to strong stop was indeterminate (Figures 11c, 12b, and 12c) and in one case the 50% cross-over point occurred at the point of voice onset (Figure 11a) and in another case 0.25 centiseconds before the voice onset (Figure 11b).

FIGURE 10

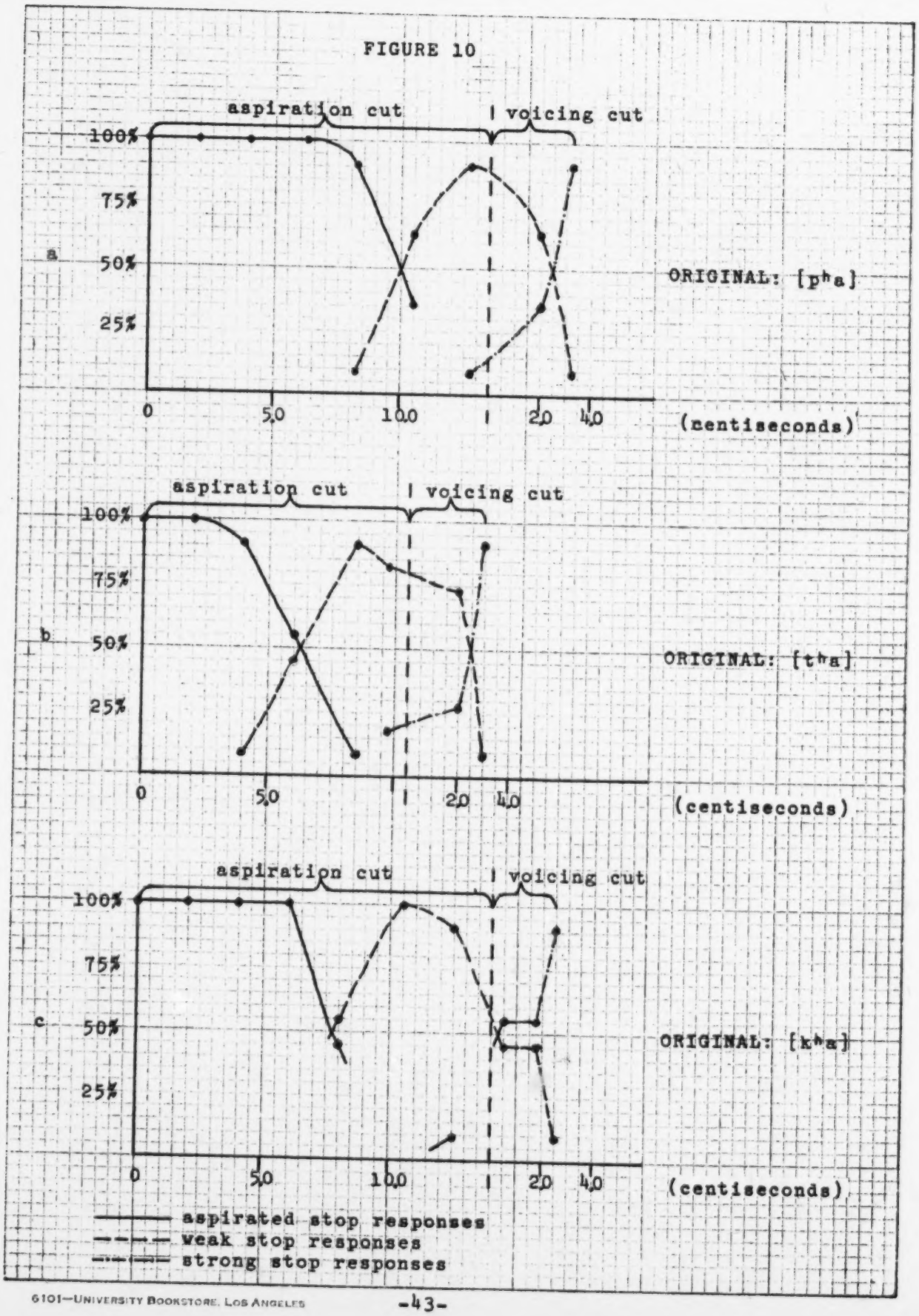

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FIGURE 11

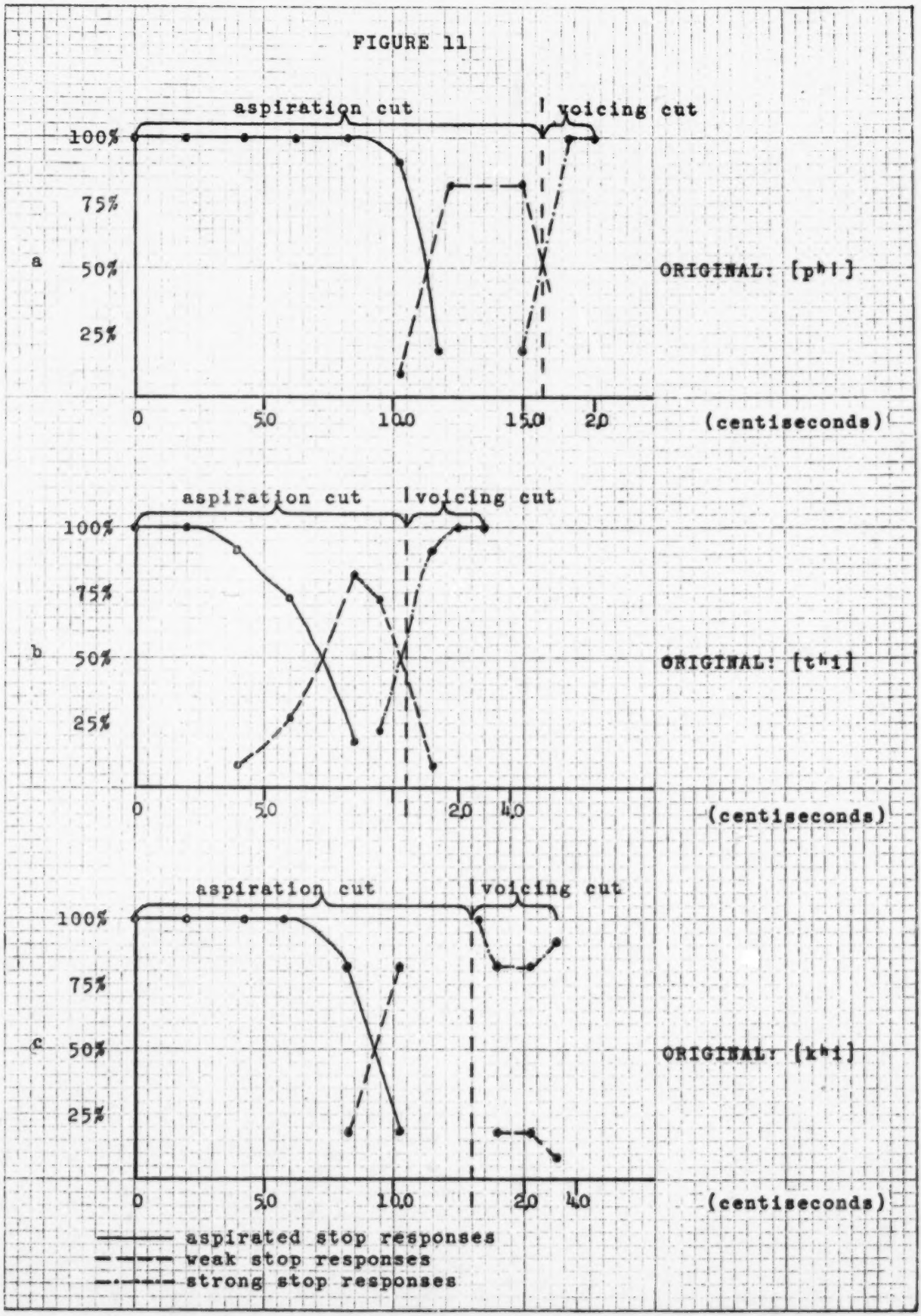
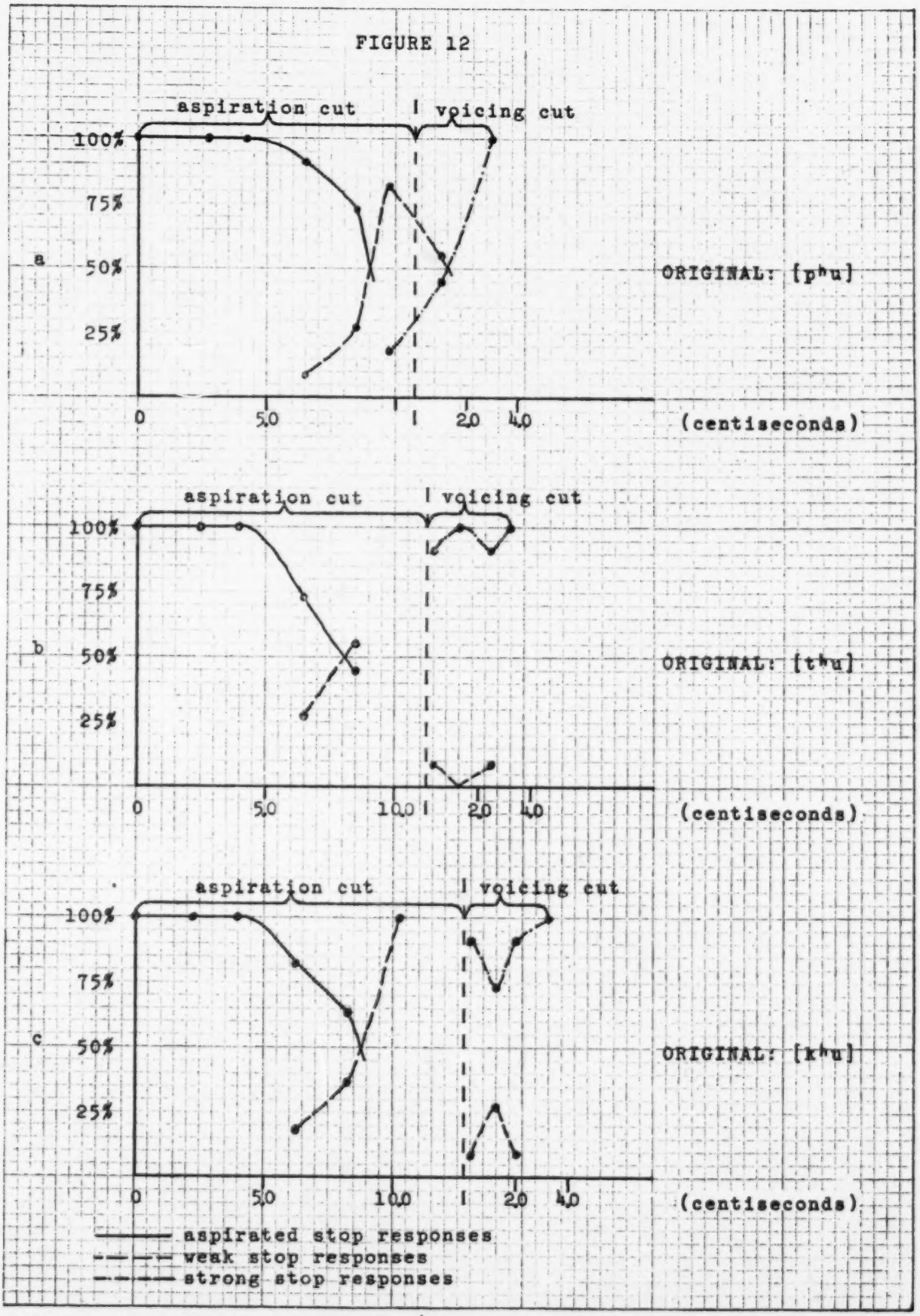

aspiration cut
voicing cut
100%
75%
a
50%
25%
ORIGINAL: [pʰi]
0
5.0
10.0
15.0
20
(centiseconds)
aspiration cut
voicing cut
100%
75%
b
50%
25%
ORIGINAL: [tʰi]
0
5.0
20
40
(centiseconds)
aspiration cut
voicing cut
100%
75%
c
50%
25%
ORIGINAL: [kʰi]
0
5.0
10.0
20
40
(centiseconds)
aspirated stop responses
weak stop responses
strong stop responses

FIGURE 12



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The waveform recordings of utterances produced in the tape cutting and splicing experiment and of the original utterances from which the synthesized utterances were made were examined in light of the native speakers' responses to them. It was found that in those cases where the 50% cross-over point from weak to strong occurred a short time before any voicing was removed (Figure 11b) or at the point of voice onset (Figure 11a) the peak amplitude of the first period of voicing was considerably greater than the peak amplitude in the other cases. Furthermore, in those cases where the 50% cross-over point was indeterminate, but where also 100%, 91%, and 100% of the responses were for a strong stop after only 0.25 centiseconds of voicing was removed (Figures 11c, 12b, and 12c, respectively), the waveform recordings of the original utterances from which they were made also exhibited a higher peak amplitude in the first period of voicing than in those where the 50% cross-over point from weak to strong stop occurred after some amount of voicing had been removed.

A comparison of the waveform patterns of those cases where the 50% cross-over point from weak to strong stop occurred after some amount of voicing had been removed further revealed that the differences in where the cross-over point occurred could be explained by the differences in waveform patterns of the original utterances. In Figure 10c where the 50% cross-over point occurred after only 0.25 centiseconds of voicing was removed, the original waveform was found to have an

amplitude build-up period of lesser duration than the others in this set. In Figure 12a where the 50% cross-over point occurred after 1.25 centiseconds of voicing had been removed, the peak amplitude of the first period of voicing was found to be about two times higher than in the original utterances of the others in this set (See Figures 10a, 10b, and 10c), while the amplitude build-up time was found to be about the same.

CONCLUSION

The results of the listening test strongly suggest that both the timing of voice onset and the quality of voice onset are important cues in the phonemic differentiation of stop consonants. In function, the timing of voice onset apparently serves to differentiate aspirated stop from weak and strong stops, but not to differentiate all three stop series from each other. The differences on average between the voice onset time of weak and strong stops does not seem to be perceptually significant. Even when voice onset time was reduced to 1 centisecond or less, which is within the range of voice onset time for strong stops, at least 75% of the responses were for a weak stop in most cases, the only exceptions being those cases where the peak amplitude of the first period of voicing was unusually high.

The cue that seems to be highly significnat in distinguishing weak stops from strong stops is the quality of voice onset. Among the differences in the quality of voice onset that we have observed are (1) the onset value of the fundamental frequency and (2) intensity. As to the differences in the onset value of the fundamental frequency, it was not possible to ascertain their significance in distinguishing strong

stops from weak stops, since in these experiments there was no way to alter fundamental frequency to any appreciable extent to determine its effect on subject responses.

As to differences in intensity characteristics, in those cases of the tape cutting and splicing experiment where in the original utterance the amplitude began relatively low and slowly built up, the 50% cross-over point from weak to strong did not occur until a good portion of the build-up time was removed, and in those cases where the amplitude began at a relatively high value, the 50% cross-over point from a weak to a strong stop occurred relatively earlier in time.

These observations seem to point out that the overall intensity characteristics at the onset of voicing is a primary cue in distinguishing weak stops from strong stops. Following a weak stop, the intensity build-up in the first few centiseconds of voicing is generally slower than that following a strong stop. Also, if the peak amplitude of the first period of voicing is relatively high following a stop (other things being equal), the consonant will tend to be heard as strong. We can summarize these findings by saying that the difference between weak and strong stops is a function of the slope of the leading edge of the intensity contour during the first few centiseconds of voicing following the stop release. Relative to the speech of a given native speaker, if the slope rises abruptly, then the stop will be heard as strong, and if the slope rises more gradually within the same time interval, then the stop will be heard as weak.

APPENDIX

Listening Test Answer Sheet

A. Warm-up Test

Note: Please circle answers.

SET 1*	SET 2*	SET 3*
1. ㅂ, ㅍ	1. ㄹ, ㄷ	1. ㄱ, ㅋ
2. ㅂ, ㅍ	2. ㄹ, ㄷ	2. ㄱ, ㅋ
3. ㅃ, ㅂ, ㅍ	3. ㄷ, ㄹ, ㄸ	3. ㄱ, ㄲ, ㅋ
4. ㅃ, ㅂ, ㅍ	4. ㄷ, ㄹ, ㄸ	4. ㄱ, ㄲ ㅋ
5. ㅂ, ㅃ	5. ㄷ, ㄸ	5. ㄱ, ㄲ
6. ㅂ, ㅃ	6. ㄷ, ㄸ	6. ㄱ, ㄲ
7. ㅂ , ㅍ	7. ㄹ, ㄷ	7. ㄱ, ㅋ
8. ㅂ , ㅍ	8. ㄹ, ㄷ	8. ㄱ, ㅋ
9. ㅃ, ㅂ, ㅍ	9. ㄹ, ㄷ, ㄸ	9. ㄱ, ㅋ, ㄲ
10. ㅃ, ㅂ, ㅍ	10. ㄹ, ㄷ, ㄸ	10. ㄱ, ㅋ, ㄲ
11. ㅂ, ㅃ	11. ㄸ , ㄷ	11. ㄲ, ㄱ
12. ㅂ, ㅃ	12. ㄸ, ㄷ	12. ㄲ, ㄱ
13. ㅍ, ㅂ	13. ㄷ, ㄹ	13. ㄱ, ㅋ
14. ㅍ, ㅂ	14. ㄹ, ㄷ	14. ㄱ, ㅋ
15. ㅍ, ㅂ, ㅃ	15. ㄹ, ㄷ, ㄸ	15. ㄱ, ㅋ, ㄲ
16. ㅍ, ㅂ, ㅃ	16. ㄹ, ㄷ, ㄸ	16. ㄱ, ㅋ, ㄲ
17. ㅂ, ㅃ	17. ㄷ, ㄸ	17. ㄱ, ㄲ
18. ㅂ, ㅃ	18. ㄷ, ㄸ	18. ㄱ, ㄲ

* ㅍ = /pʰ/ ㅌ = /tʰ/ ㅋ = /kʰ/

ㅂ = /p/ ㄷ = /t/ ㄱ = /k/

ㅃ = /P/ ㄸ = /T/ ㄲ = /K/

B. Listening Test

IA.

1. ㅂ, ㅃ
2. ㅂ, ㅍ
3. ㅂ, ㅍ
4. ㅂ, ㅍ
5. ㅂ, ㅍ
6. ㅂ, ㅍ
7. ㅂ, ㅍ
8. ㅂ, ㅃ
9. ㅂ, ㅃ

IB.

1. ㄹ, ㄷ
2. ㄹ, ㄷ
3. ㄹ, ㄷ, ㅍ, ㅂ
4. ㅂ, ㅃ, ㄷ, ㄸ
5. ㄹ, ㄷ, ㅍ, ㅂ
6. ㄷ, ㅂ, ㄸ, ㅃ
7. ㄷ, ㅂ, ㄹ, ㅍ
8. ㄷ, ㅂ, ㄸ, ㅃ

IC.

1. ㄲ, ㅃ, ㄱ, ㅂ
2. ㅋ, ㄱ
3. ㄱ, ㅂ, ㅋ, ㅍ
4. ㅍ, ㅋ
5. ㅍ, ㅋ
6. ㅋ, ㅍ, ㄱ, ㅂ
7. ㄱ, ㅂ, ㅋ, ㅍ
8. ㄲ, ㅃ, ㄱ, ㅂ
9. ㄱ, ㅂ, ㅋ, ㅍ
10. ㄲ, ㄱ, ㅃ, ㅂ

IIA.

1. ㅍ, ㅂ
2. ㅃ, ㅂ
3. ㅂ, ㅍ
4. ㅂ, ㅍ
5. ㅂ, ㅍ
6. ㅂ, ㅍ
7. ㅃ, ㅂ
8. ㅃ, ㅂ
9. ㅍ, ㅂ
10. ㅍ, ㅂ

IIB.

1. ㄷ, ㅂ, ㄸ, ㅃ
2. ㄷ, ㅂ, ㄹ, ㅍ
3. ㄷ, ㅂ, ㄹ, ㅍ
4. ㄹ, ㄷ
5. ㄸ, ㄷ
6. ㄷ, ㄸ
7. ㄷ, ㄸ
8. ㄹ, ㄷ
9. ㄹ, ㄷ

IIC.

1. ㄷ, ㄱ, ㄸ, ㄲ
2. ㄸ, ㄲ, ㄷ, ㄱ
3. ㅍ, ㅋ, ㅂ, ㄱ
4. ㅍ, ㅋ, ㅂ, ㄱ
5. ㅂ, ㄱ, ㄷ, ㅃ, ㄲ, ㄸ
6. ㅃ, ㄲ, ㄸ, ㅂ, ㄱ, ㄷ
7. ㅋ, ㄱ
8. ㅋ, ㅍ, ㄱ, ㅂ
9. ㅋ, ㅍ, ㄱ, ㅂ
10. ㅋ, ㅍ, ㄱ, ㅂ

IIIA.

1. ㅍ, ㅂ
2. ㅍ, ㅂ
3. ㅍ, ㅂ
4. ㅃ, ㅂ
5. ㅂ, ㅍ
6. ㅂ, ㅃ
7. ㅂ, ㅃ
8. ㅍ, ㅂ

IIIB.

1. ㅃ, ㄸ, ㅂ, ㄷ
2. ㄹ, ㄷ
3. ㅃ, ㄸ, ㅂ, ㄷ
4. ㅃ, ㄸ, ㅂ, ㄷ
5. ㅂ, ㄷ, ㅍ, ㄹ
6. ㅂ, ㄷ, ㅃ, ㄸ
7. ㅂ, ㄷ, ㅍ, ㄹ
8. ㅍ, ㄹ, ㅂ, ㄷ
9. ㅂ, ㄷ, ㅍ, ㄹ

IIIC.

1. ㄲ, ㅃ, ㄱ, ㅂ
2. ㄱ, ㅂ, ㅋ, ㅍ
3. ㄱ, ㅂ, ㅋ, ㅍ
4. ㄱ, ㅂ, ㄲ, ㅃ
5. ㅋ, ㄱ
6. ㄱ, ㅋ
7. ㅋ, ㄱ, ㅍ, ㅂ
8. ㄱ, ㅋ
9. ㄲ, ㅃ, ㄱ, ㅂ
10. ㄲ, ㅃ, ㄱ, ㅂ

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13. ABSTRACT

In Korean nine stop consonants--the aspirated bilabial, dental, and velar stops (/p^h, t^h, k^h/); the weak bilabial, dental, and velar stops (/p, t, k/); and the strong bilabial, dental, and velar stops (/P, T, K/)--contrast with each other. In order to determine those acoustic features involved in the manner differentiation of these stops, a fairly large amount of data was collected, and a number of speech synthesis experiments were carried out using the tape cutting and splicing method.

These studies revealed that aspirated stops are distinguished from weak and strong stops primarily by the timing of the voice onset. Aspirated stops were found to be 2.4 to 5.3 times longer than weak stops and even longer than this compared to strong stops.

The cues for the distinction between weak and strong stops seem to be (1) the intensity build-up in the first few centiseconds of voicing following stop release, which is generally slower with weak stops than with strong stops and (2) the peak amplitude of the first period of voicing. These findings indicate that the difference between these stops is a function of the slope of the leading edge of the intensity contour during the first few centiseconds of voicing following the stop release. Relative to a given speaker, if the slope rises abruptly, the stop will be heard as strong, and if it rises gradually, the stop will be heard as weak.

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	ROLE	WT	ROLE	WT	ROLE	WT
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